LAND USE AND WATER QUALITY IN EL CORPUS, CHOLUTECA, HONDURAS

By

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The research report: “Land Use and Water Quality in El Corpus, Choluteca, Honduras” is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN FORESTRY.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Cheque pues…

ABSTRACT

The intent of this study is to examine the current condition of the Rio Calderas watershed in southern Honduras. High rural population densities, intensive land use for traditional annual crops, the expansion of cattle pasture as an economic alternative and precious metal mining all threaten the quality of surface water in the area. A very pronounced dry season places further stress on water supplies for up to five months of the year.

Land use was classified in two subwatersheds, the Quebrada San Juan and the Quebrada El Sabroso. Agriculture, including permanent crops, was found to occupy 79% of the San Juan and 49% of the El Sabroso watershed land areas. Chemical, biological, and physical characteristics of stream water were examined at eleven sample sites. Field measurements of water flow, conductivity, pH and turbidity were used in conjunction with laboratory analyses to identify trends in surface water quality. Biological contamination, indicated by fecal coliform bacteria, was identified at all sample sites. Erosion was identified as contributing significantly to water turbidity levels in the Q. San Juan; overall increases in conductivity with respect to stream position suggest steady water quality degradation. Active and historical gold mining activities were found to contribute to water quality degradation in the Q. El Sabroso, and evidence indicates acid mine drainage (AMD) is causing increased levels of conductivity, overall water hardness and sulfates. The urban area of El Corpus was found to contribute to increased levels of nitrates due to contamination from human waste. Elevated conductivity and sulfate levels were also found, suggesting the presence of AMD from the original gold mine established by the Spanish colonists in the 1500s.

Chapter 1. Introduction

Environmentalism as a movement and collective consciousness is common to many nations of the developed world. When environmental news from developing countries is reported, it is often of a negative nature. The headlines report mass starvation due to drought and crop failure, virgin rain forests being incessantly cleared and burned, coral reefs being destroyed and threatened species being hunted into extinction. Judging solely by news reports, one could be fooled into thinking the people of developing countries cared little for the environment.

What I found when I arrived in Honduras in 2003 was quite the opposite. Whether the environmental movement in Honduras evolved on its own or received a huge push from the destruction brought by Hurricane Mitch in 1998 is unclear. What is clear is that the natural environment is on everyone’s mind; even the slogan on the national license plate urges people to care for the forests. National newspapers publish front-page investigations into illegal logging. The youngest schoolchildren know that their drinking water is somehow connected to forested mountains.

Water especially is on everyone’s mind. It was quickly on *my* mind during my Peace Corps training, when the municipal water system of the city I lived in could only deliver water to the house for a few hours per week. After training, I was assigned to El Corpus, Choluteca, in the far south of the country. I began my assignment as a Protected Areas Management volunteer there in December, a time of the year when the trees are green and the streams still flow with vigor. Four months later, as I walked along a dry stream bed filled with fallen leaves, smoke from burning fields filled the air. The only water to be seen was standing in a few algae-filled puddles, and in buckets being carried from the stream back to rural houses. Water issues seem especially pressing in southern Honduras in April.

The focus placed on water in Honduras by development agencies, government projects and concerned citizens is what started me thinking about water. The construction of water systems to bring clean water to small villages is a common focus of development agencies in Honduras. A 1991 Honduran government report stated that 85% of Honduran families relied on surface water for domestic consumption needs, and that only 30% of the water in Honduras met Pan-American Health Organization standards (Rivera 2004). Many rural water systems are gravity-fed, bringing water from a spring at higher elevation to clusters of homes. They require a common vision among the residents in planning, building, and maintaining these systems. But many residents live outside of ‘town’. The population of Honduras is largely rural, and is spread throughout the countryside. Many residents do not receive water piped to their home from that relatively clean source higher in the hills. These are the families who haul water from a stream or common well to their house and who spend hours standing in the river washing clothes. Downstream from their homes, other residents do the same. Pipes and diversions carry water away from the streams to irrigate small parcels of crops.

In El Corpus, I observed many families relying on stream water for their household needs. At times, the stream that runs along the road from the city appeared to be no more than a trickle, disappearing between the rocks. In places families would construct small dirt and rock dams to trap a pool of water so they could wash their clothes or fill a bucket. At other, rainier times, the trickle became a powerful brown surge spilling over the road and washing out small bridges, stranding people on one side or the other for hours until the current subsided.

The city of Choluteca, with a population over 100,000 people, pipes around 30% of its water from mountain spring sources in El Corpus to the city. For a time, the city considered building a second system to pipe water from that roadside river coming from El Corpus to augment its needs (Montoya, pers. comm.). In the valley, irrigation water is at a premium for large-scale agriculture. In the Gulf of Fonseca, where the rivers meet the Pacific Ocean, deteriorating water quality and quantity threatens estuary integrity, an environmental problem for the mangrove ecosystem and an economic problem for both traditional fishermen and the booming shrimp farms (PROGOLFO 1999).

The threats to water quality in El Corpus are many. They include deforestation, mining, burning, soil erosion, and biological wastes from humans and livestock. In this study I examine common indicators of water quality and relate them to land use in the El Corpus watershed. In Chapter two, I introduce Honduras and some of the issues relevant to current environmental and economic conditions. In Chapter three, the Honduran South and the El Corpus study area are introduced. Study sites examined and methods used are described in Chapter four. Chapter five provides an introduction to the type and quality of data collected. Chapter six describes the results and discusses their implications. In Chapter seven I present implications and recommendations.

Chapter 2: Country Background for Honduras

Geography and Administration

A predominately mountainous Spanish-speaking country with a large rural population, Honduras is the second largest country in Central America. It is bordered by Guatemala, El Salvador and Nicaragua, and has coastline on both the Atlantic (Caribbean Sea) and Pacific (Gulf of Fonseca) Oceans (Figure 1). Total land area is 111,890 km^2, with an additional 200 km^2 of water area. This makes Honduras roughly the size of the state of Tennessee (Central Intelligence Agency 2005). Its highest point is found in the western portion of the country, at 2870 m Cerro de la Minas in Celaque National Park. It possesses only one large natural inland lake, Lago Yahoa, but has 820 km of ocean coastline, mostly along the Caribbean to the north. Honduras also controls three large predominately English speaking islands off the country's north coast, Guanaja, Roatan and Utila.

The capital of Honduras is Tegucigalpa, located in the southern central region of the country. Other major urban centers include San Pedro Sula and La Ceiba in the northern portion of the country and the city of Choluteca in the southern portion. The country is divided in to 18 departments for administrative purposes, roughly the equivalent of US States. Each department is further broken down into *municipios*, or counties, and these further into *aldeas*, or villages. Each *municipio* has its administrative seat in a town of the same name, and this town is usually, although not always, the largest population center in the *municipio* as well. These counties are administered by elected *alcaldes*, or mayors, who are the head of local government.

Figure 1. Map of Honduras (CIA 1985: Courtesy of the University of Texas Libraries, The University of Texas at Austin).

Physical and climate

The nation's terrain is characterized by steep and extensive mountains, with few large areas of flat valley land. Of the total land area, 79% is mountains above 600 m elevation and 15% is hills between 150 and 600 m; valleys approaching sea level constitute only 6%. More than three fourths of the country is covered by slopes of 25% or greater (Harcourt and Sayer 1996). The fertility of the land is poor as well, making it poorly suited for agriculture. Missing are the rich volcanic soils found in neighboring Guatemala, El Salvador and Costa Rica. Intensive annual crops should only be grown on about 11% of the land area, perennial crops and pasture on another 9%, and mixed forest plantation and perennial crops on another 13% (Leonard 1987).

The climate is described as subtropical to tropical in the coastal lowlands and temperate in the interior uplands. Two main seasons exist; the rainy season which runs generally from June to November, and the dry season from December through May. Elevation and topography have the greatest effect in determining local climatic conditions. Temperatures on the northern and southern coasts average around 27 to 28^{o}C, while interior mountains maintain temperatures near 21^{o}C. Rainfall likewise varies; on the coasts it can average over 2500 mm per year, while interior valleys may receive only around 1000 mm (Encarta 2005).

Population

Honduras had an estimated mid-2005 population of 7.5 million inhabitants. The population is 86% *mestizo*, 2% white, 2% black Garífuna (descendents of African slaves marooned on the north coast), and about 10% indigenous Amerindian. Indigenous tribes include the Lenca in the western highlands, the Chorti Maya in the far-western corner near the Guatemalan border, and the Miskito and Pech in the eastern region. The rate of natural population increase of 2.8% is down from a population growth rate of 3.71% in 1981-1982. The current rate of increase still remains tied for the highest in Central America and is exceeded worldwide only by a handful of nations in Africa (Population Reference Bureau 2005, DeWalt and Stonich 1999). Half of the population is less than 19 years old (Central Intelligence Agency 2005). Education is compulsory through the primary level (6th grade), yet only about 30% of children continue to secondary education, and only 8% continue on to university (US Library of Congress 1993).

High population growth combined with poor education has had many negative effects. Continued migration to the major urban centers, Tegucigalpa and San Pedro Sula, has resulted in large urban hillside slums with hundreds of thousands of unemployed or underemployed, mostly youthful, citizens (Figure 2). The resulting increase in crime, especially organized crime in the form of *maras* (street gangs), has been especially problematic. The current president, Ricardo Maduro, was elected on a platform that promised to combat the high crime rates, but the government's efforts have met with mixed results. Following an initial success, the policies have only shown a minimal improvement in long-term crime statistics (US Department of State 2005).

Figure 2. Neighborhood on a precarious hillside in Tegucigalpa. The neighborhood originally extended further to the left prior to landslides caused by Hurricane Mitch.

Agricultural land access and use

Unequal land and wealth distribution, a problem in many developing nations, is an acute problem in Honduras. In 1980, 60% of the Honduran population was directly involved in agriculture (DeWalt and Stonich 1999). Being dependent on agriculture generally implies having access to productive lands, however in Honduras, as in many agricultural developing countries, the population's access to land is very unequal. On the north coast, for example, large tracts of fertile valley land are planted with banana and palm oil. These lands have been in the hands of foreign-controlled companies for years, notably Standard Fruit (later Dole) and United Fruit Companies (Chiquita brands). The economics of banana production dictated US – Honduran relations, and hence Honduran national politics, since time immemorial.

Modern times have not improved upon the historical record of land distribution. In terms of access to land, 4% of Honduran landowners control 56% of the farmland (Norsworthy and Barry 1994). In 1980, nationwide about 64% of agricultural producers had access to 5 ha or less of land, while only 10 to 12% had access to 50+ ha (DeWalt and Stonich 1999). For the small landholder, or *campesino*, the consequence of large landholdings and export-oriented agriculture on the flat valley lands is that he is pushed onto the less desirable hillside tracts.

Obviously, small and large landowners have differing priorities and will use their share of land differently. In a study of highland communities in 1983, DeWalt and Stonich (1999) found that 80% of those farmers who owned less than 1 ha of land, and 51% of those who owned between 1 and 5 ha, planted that land in food crops such as maize, beans and sorghum. By contrast, only 6% of those who owned more than 20 ha did so. Large landowners, in order to maximize profits, dedicate land area to export crops and cattle production. DeWalt (1985) calculated that average profit from the sale of one steer exceeded that of several *manzanas* (1 *manzana*=0.69 hectares) of grain production in the municipality of Pespire, in southern Honduras. Cattle are much less labor intensive than other forms of production, and consequently cattle pasture has become a common land use in many areas of the country. According to the Honduran Central Bank, 48% of valley lands were sown in pasture for cattle (USAID 1990 as cited in DeWalt and Stonich 1999), and 30% of all land is dedicated to cattle ranching (Leonard as cited in Norsworthy and Barry 1994). Cattle do relatively poorly in Honduras, however, as the stocking rate in Honduras is .65 head per hectare, compared with 2.36 in El Salvador. Honduran cows' annual milk yield is lower as well, producing only 606 kg of milk per year, the lowest yield in Central America (Leonard 1987).

Economy

The Honduran economy has traditionally been a poor performer. In 2004, the per-capita GDP was $2800 (Central Intelligence Agency 2005). Often termed a "banana republic", Honduras' early post-independence economy was closely tied to exports of that crop, and related profits stayed with the banana plantations' foreign (US) owners. Other important sectors of the economy have relied on the extraction of natural resources, such as forest and mineral exploitation. The modern Honduran economy is still heavily reliant on export-oriented agriculture, with bananas, shrimp and coffee production as its top three foreign-currency earners. Many of these concerns are owned or managed by US and other foreign companies, as are many manufacturing and assembly operations.

Textile assembly has become a major manufacturing concern, especially in the northern industrial capital of San Pedro Sula. Although occasionally the focus of foreign protests, usually concerned with workers' conditions, the *maquilas* (factories) have become an important source of employment and foreign capital investment for Honduras.

The annual inflation rate in Honduras is approximately 7%, and the nation carries a staggering public debt that represents 74% of its GDP (Central Intelligence Agency 2005). Recently Honduras has re-qualified for relief under the Heavily Indebted Poor Countries (HIPC) initiative, which stands to relieve the country of approximately $1 billion of its foreign debt load. How this obligation reduction will be utilized by the government to increase the standard of living of its citizens is unclear. It is estimated that of urban households, 37% are currently considered to be living in 'extreme poverty'; the corresponding figure for rural households was 61% (Government of Honduras 2000).

The prevalence of rural poverty especially is a problem that is poorly addressed by the government. The recent passage of the Dominican Republic-Central American Free Trade Agreement (CAFTA) with the United States was not a universally celebrated event. The proposal stands to increase exports in certain sectors of the Central American economy, notably manufacturing. It also seeks to liberalize many portions of those countries' markets. Analysts are skeptical, however, that CAFTA will have a positive effect on the rural poor. Protests against the passage of CAFTA were widespread in Central America, as many believe CAFTA represents the latest attempt by the United States to dominate every aspect of the political and economic systems of poor countries in its backyard. Honduras, however, was one of the first countries to ratify the agreement.

Natural Resources and Environment

Forests

The nation's topography, while less than ideal for agricultural cultivation, allowed a large variety of natural ecosystems to develop. In the north, at elevations up to 750 m on the Caribbean coast, humid tropical forest is found in areas with an excess of 2000 mm of annual rainfall and no distinct dry season. These are evergreen hardwood forests and reach canopy heights of 60 meters (Harcourt and Sayer 1996). In the interior highlands, at elevations between 600 m and 1800 m, pine and oak forests predominate. These forests are found throughout central and western Honduras. Occasional lowland pine communities are also found in portions of the Moskitia, a sparsely settled area of eastern Honduras bordering Nicaragua. In the southern portion of the country, tropical dry forests are dominant in the lowlands, transitioning to pine forests at elevations of 800 m. At the highest elevations throughout the country, between 1400 m and 2800 m, cloud forests occur. These cool and moist forests are characterized by a mixture of conifer and broadleaf trees hosting a variety of epiphytes and vines in the middle and upper canopy. Coastal mangrove forests are found both in the Gulf of Fonseca on the Pacific Ocean and along portions of Caribbean coast.

Forests in Honduras have been subjected to intense human pressure for smallholder agriculture, wood products and cattle grazing. Overall, it is estimated that Honduras lost between one-quarter and one-third of its forests from 1964 to 1990 (Richards 1996). Since 1990 that trend has continued. Between 1990 and 2000, Honduras lost an additional 59,000 ha of forest per year, or 1% of its forest cover per year (FAO 2005). Although 90% of the nation's forest products come from conifer forests (Figure

3), areas of broadleaf forests are being deforested most rapidly. Between 1965 and 1990, broadleaf forests were reduced from 37,592 km^2 to 23, 434 km^2, a loss of almost 38% (Harcourt and Sayer 1996). This is a result of the encroachment of the agricultural frontier, especially in the eastern part of the country, as well as cattle grazing and high-grading logging practices in the hardwood forests. The high rate of broadleaf deforestation occurs even though most of the nation's parks and preserves were designed to protect broadleaf forests areas.

Figure 3. Timber extraction in pine forest by relatively small-scale operators.

The Honduran National Protected Areas System (SINAPH) was created in 1980 with the designation of La Tigra National Park. This cloud forest park, located in the peaks above Tegucigalpa, was created with the realization that deforestation was threatening to drastically affect the capital's water supply. As is the case in many developing nations, designated protection status means little in Honduras given limited law enforcement (Brower 2000). Encroachment for agriculture and wood extraction occurs within established parks and reserves even though it may be specifically prohibited (Figure 4). The number of protected areas reported for Honduras varies depending on whether areas with lower-level protection status, such as multiple-use and archaeological areas, are included, but approximately 70 major parks and wildlife reserves protect over 20% of the national land area, including the 8,300 km^2 Río Plátano Biosphere Reserve, a United Nations World Heritage Site (EarthTrends 2003).

Figure 4. Cleared land for hillside agriculture and grazing inside the Río Plátano Biosphere Reserve.

Minerals and mining

Mining has been an important part of the Honduran economy since the arrival of the Spanish in the 1500s. Mines have historically been foreign-owned and financed operations, with the resulting profits leaving the country. Gold mines proved profitable for the Spanish in western Honduras in the 1530s and 1540s. Subsequent silver discoveries in central Honduras in the 1580s led to the founding of the city of Tegucigalpa and numerous smaller communities, including El Corpus in southern Choluteca. From 1882 to 1954, the New York and Honduras Rosario Mining Company extracted $60 million worth of gold and silver from mines above Tegucigalpa in and around what is now La Tigra National Park. Mining has followed a boom-and-bust cycle, declining in importance throughout the country for a time then reviving at various intervals based on economic and political factors, such as the world market price for minerals and the country's investment climate.

In recent history, mining activity has increased once again. The trend began in 1996 and 1997, as the government encouraged foreign investment as part of its obligations as an HIPC. Following Hurricane Mitch in 1998, the desire to attract foreign capital intensified, as Honduras struggled to reconstruct critical infrastructure and repay crushing foreign debt. The National Congress passed a series of laws opening coastal areas to tourism development, selling operation concessions for airports and seaports, and reforming the mining code. The passage of the General Mining Law re-asserted the government's right to all minerals and its exclusive power to transfer subsurface exploration and exploitation rights. It was estimated in 2001 that over 30% of the country's territory had been leased for mining (CESR 2001). The country's highest production was in lead, followed by zinc, gold, silver, cadmium and antimony (Velasco 2000). The steady increase in the price of gold to over $500 per ounce in late 2005, the highest level in 24 years, has once again made many previously unprofitable operations potentially feasible.

The General Mining Law continues to be controversial, especially in communities affected by mineral extraction. Among the problems frequently mentioned are low wages, little regard for standards of worker safety and protection, the ability of companies to petition for the forcible removal of residents and entire communities, and excessive environmental contamination. Many large gold mines use a heap-leach extraction process, which can recover up to 97% of ore’s gold value through the use of highly toxic cyanide; this has sparked growing concern over water contamination and mine worker health. The stringency of environmental impact monitoring and reporting has been called into question as well, as mining companies themselves pay for the completion of the required initial Environmental Impact Statement (EIS) upon which the government relies to approve or deny a company’s proposed mining permit, an obvious potential conflict of interest. As of 2001, no mining permit had ever been refused (CESR 2001).

The recurring theme of exploitation by foreign interests is one reason that Honduras is one of the poorest countries in the western hemisphere. The fragility of its resources, and the extent to which the population is dependent on those resources, is another. The pattern of environmental degradation seen throughout the country is especially prevalent in southern Honduras. The study area of El Corpus, in the southernmost Department of Choluteca, is no exception.

Chapter 3: Study Area Background:

Southern Honduras and El Corpus

Geography

Southern Honduras

Throughout the country Hondurans refer to *El Sur*, or the South, a region of the country that includes the area of Choluteca and Valle Departments as well as the southern parts of Francisco Morazán and El Paraíso (Figure 5). The Honduran South is a geographically, socially and economically distinct entity in the minds of those who live within and without the region (Boyer 1982). The region, which comprises approximately 5% of the national territory, is bordered to the west by El Salvador, the east by Nicaragua and the south by the Pacific Ocean.

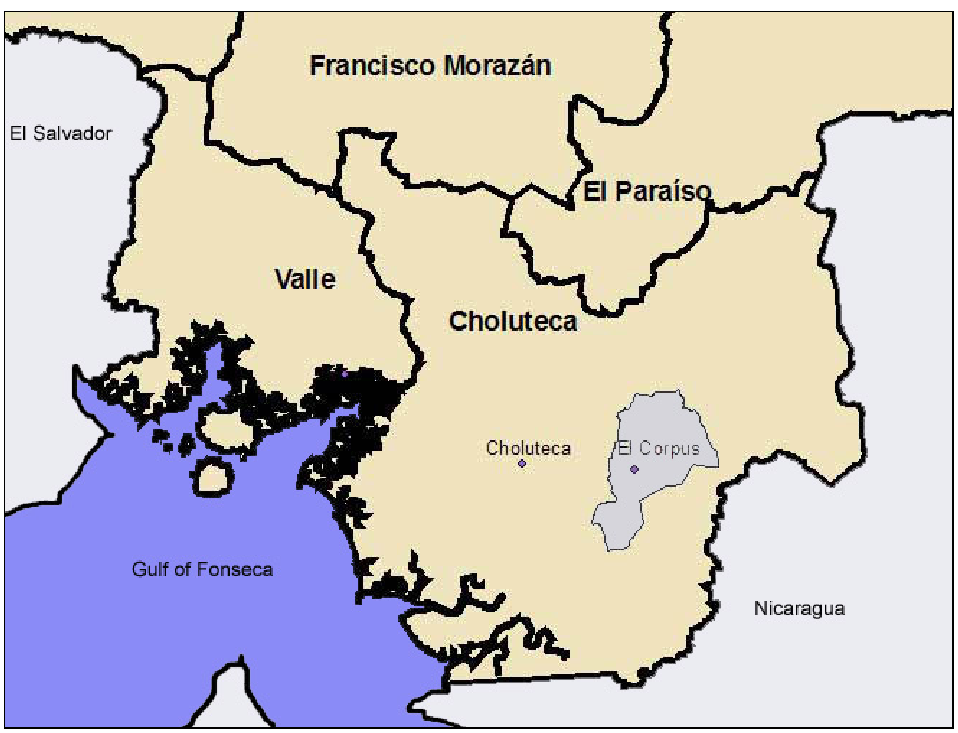

Figure 5. Map of southern Honduras and the *municipio* of El Corpus (adapted from CIAT 2001).

The coastal plain comprises over 41% of the region's area, gently sloping towards the Gulf of Fonseca (Figure 6). The remaining 59% of the South's land area is mountainous, with elevations up to 1400 m above sea level. The region's major hydrological features, besides the Gulf, are the river systems draining from the mountains. The largest river in the region, the Río Choluteca flows through the city of Tegucigalpa and reaches its terminus at the Gulf of Fonseca after draining an area of 9013 km^2. Other major rivers draining the south include the Río Nacaome and Río Sampile, the Río Goascoran on the Salvadoran border, and the Río Negro on the border with Nicaragua; together these five rivers drain 13% of the land area of Honduras (Harcourt and Sayer 1996).

Figure 6. Looking east from El Corpus across the Choluteca valley.

The Gulf of Fonseca is a narrow, island-filled water body bordered by three nations, Honduras, El Salvador and Nicaragua. Where warm Pacific Ocean waters meet the rivers draining the uplands, mangroves, tidal flats and lagoons make up an estuarine system on approximately 1000 km^2 of land along the Gulf. The land immediately surrounding the coastline is used for export-oriented production, including melons, sugarcane and shrimp farming. Shrimp farming in particular was Honduras' fastest-growing non-traditional export during the 1980s, growing to become the third principal export crop after bananas and coffee in the early 1990s (Samayoa *et al.* 2000). Today, shrimp exports outrank even coffee production in terms of economic importance (Central Intelligence Agency 2005). Quality mangrove forests declined 22% between 1973 and 1993, and the shrimp industry is blamed for at least 32% of those losses (Stonich and DeWalt 1996). The Gulf estuaries, and subsequently the booming shrimp industry, depend on nutrients delivered by the river systems; water quality entering the Gulf has degraded largely due to the heavy sediment loads caused by upstream soil erosion (DeWalt 2000, Thurow and Smith 1998). The coastal forests have also been heavily impacted by subsistence use over time, as mangrove trees were used for firewood and the land converted to agriculture.

The city of Choluteca, which is Honduras' fourth largest city and is the capital of the department of the same name, has a population of over 100,000 inhabitants and is located on the banks of the Río Choluteca about 30 km from the coastline. The city sits at an elevation of approximately 35 meters above sea level in the southern coastal plain, which is bordered by mountain ranges to the north, south, and east. Transportation is facilitated by the Pan-American Highway, connecting Honduras to El Salvador and Nicaragua, as well as a highway to Tegucigalpa. There are no rail connections in southern Honduras, but the area is served by one sea port located at San Lorenzo, in the Department of Valle.

Although the South includes a relatively large amount of much-coveted flat land in otherwise mountainous Honduras, the region's climate precludes large-scale agriculture without irrigation. Much of the flat valley land is owned by large land-owners, partly a result of the cotton boom, which started in the 1940s and ended in the late 1980s, as well as the continuing prevalence of the cattle industry (Stonich and DeWalt 1996). In addition to cattle grazing, today's major export-oriented crops, often grown with irrigation, include melons and sugarcane.

El Corpus

The *municipio*, or municipality, of El Corpus is located approximately 17 km east of the city of Choluteca and covers an area of 233.9 km^2 (EPYPSA 2002). The municipality is mountainous throughout its extent, and the elevation of the town of El Corpus, the municipal capital, is approximately 390 m (Figure 7). Elevations elsewhere in the municipality range from 80 meters where the foothills meet the Choluteca valley, to over 1000 meters at the eastern border with the municipality of San Marcos de Colon.

Figure 7. The town of El Corpus.

Cerro Guanacaure, a 1007 meter peak to the west of the town of El Corpus, is protected as a nationally declared Multiple Use Area, the lowest classification of protected area currently in the Honduran Protected Area System. First placed under the jurisdiction of COHDEFOR in 1989 as a Forest Reserve Zone, its current status minimally provides for its protection. The name *Guanacaure*, an indigenous word, means "hill filled with water" (Gareau 2004). Created with the intent of protecting critical watersheds, the reserve's nineteen square kilometers protect drinking water sources for numerous small communities in the vicinity. It also provides between 30 and 40% of the municipal water for the city of Choluteca (Montoya, pers. comm.).

History

The history of the earliest settlements in southern Honduras is less well-known than other areas of the country. It is believed that the pre-contact population was comprised of three groups, the Chorotegas, the Ulvas, and the Poton, who immigrated from Mexico and South America. The arrival of the Spanish in the early 1500s resulted in permanent settlements in the Choluteca Valley as early as 1522 (Stone 1973 as cited in Boyer 1982). The mountain regions were 'discovered' a few years later as the Spanish found gold and used Indian labor to extract it. El Corpus was one of the first and most productive of these mining centers, and the original gold mine established by the Spanish is still visible today, just downhill from the Catholic church in the center of town.

Although its first important commodity was gold, the South's main export products also included cattle and indigo dye. Mining, livestock and indigo plantations were the staples of the economy, and provided the bulk of employment opportunities.

Jobs were filled by a growing population of *mestizos,* those of mixed Spanish and native blood. The collapse of the world indigo market in the mid-1800s changed the economy profoundly, and the region became an area of large, although relatively unprofitable, cattle operations with some smallholder production in the marginal areas (Boyer 1982). The highland areas surrounding the city of Choluteca were originally forested and sparsely settled. As the lowland population increased, more settlements appeared in the hills; families also began arriving from El Salvador and Nicaragua and establishing farms of 100 to 150 *manzanas* (1 *manzana* = 1.73 acres) in small rural communities called *aldeas* (Boyer 1982). The population grew steadily with time, and more land was occupied by later settlers until land became scarce. The occasional peasant cultivator occupied the smaller niches not taken by larger landowners.

Population Densities and Growth Rates

The South has traditionally been the most densely settled region of the country. Highland areas have historically borne higher population densities than the coastal plain and have grown disproportionately faster than nearby lowland areas. Boyer (1982) reports population statistics comparing two adjacent areas, one in the highlands and the other in adjacent lowlands. While the population density of the lowland study area increased from 6.2 to 19.2 persons/km^2 from 1901 to 1950, the same period saw the highland population density rise from an already-higher 24.3 persons/km^2 to 63. Some highland areas have population densities as high as 160 persons/km^2 (Stonich and Dewalt 1996).

The mountain *municipio* of El Corpus was no exception to these trends (Table 1). In 1988, population densities in El Corpus are well above the national average of 39.1 inhabitants per km^2 as well as the regional average for the South (72 inhabitants per km^2).

Year of data set	1974	1988	2001
Population	15,238	20,884	21,874
Population density per km^2	65	89	94
Increase from previous data set (%)		37.05	2.70
Mean annual growth since previous data set (%)		2.25	0.36

Table 1. Population, density and growth in El Corpus, Choluteca. EPYPSA (2002).

High population pressures have placed great strain on the natural environment. Limited available land for cultivation has led to demographic changes, one of which is the out-migration of residents from the southern region to other parts of the country, either to the major cities of Tegucigalpa and San Pedro Sula, or to seek new land for cultivation, most notably in the department of Olancho and even in the Río Plátano Biosphere Reserve. Between 1974 and the late 1980s, out-migration averaged 1.3% annually (Stonich and DeWalt 1996).

Climate

Southern Honduras is generally considered to be the hottest region of the country. The average daily temperature for the city of Choluteca is 28.6^{o}C (World Climate 2005). The climate is widely perceived to be changing. Residents in both Choluteca and El Corpus declare that temperatures have risen noticeably over their lifetimes, and rainfall has become either scarcer or at least more variable. Some data corroborate this. Almendares (1993) reports weather station data indicating that the mean annual temperature in Choluteca rose 7.5°C between 1972 and 1990, with most of that change occurring over the span of a few years in the early 1980s. It is difficult to assess the accuracy of that data, and there is no explanation given for the sudden increase. Local residents, however, are often quick to identify deforestation, fires and general global warming as the reason Choluteca is a warmer place than it used to be. The municipality of El Corpus is somewhat cooler than the lowlands, as its climate is affected by local topography. Over a recorded period of 1970-1980, the average annual temperature was 25.5°C, with the coolest months being October-January at 24°C and the warmest month being March at 28°C (Mayorga 1989).

Rainfall in the study area follows the tropical pattern of wet and dry seasons seen elsewhere in Honduras. The rainy season in the South generally begins in mid-May and ends in early November. Rainfall is not constant throughout that period, however, and generally there is a pronounced *cubicula*, or little dry season, during the month of July. Weather data reported for the city of Choluteca, averaged over almost 30 years, reports annual rainfall of 1,755 mm (World Climate 2005). A weather station kept at Agua Fría, at an elevation of 700 m, reported an annual average rainfall of 2,659 mm over the period 1978-1988. Mayorga (1989) also reports potential evapotranspiration measurements taken in the city of Choluteca; the monthly average varies from 273.2 to 147.2 mm with an average annual figure of 2,453 mm (Figure 8). It is apparent that the dry season, which runs from mid-November through April, results in an acute moisture deficit.

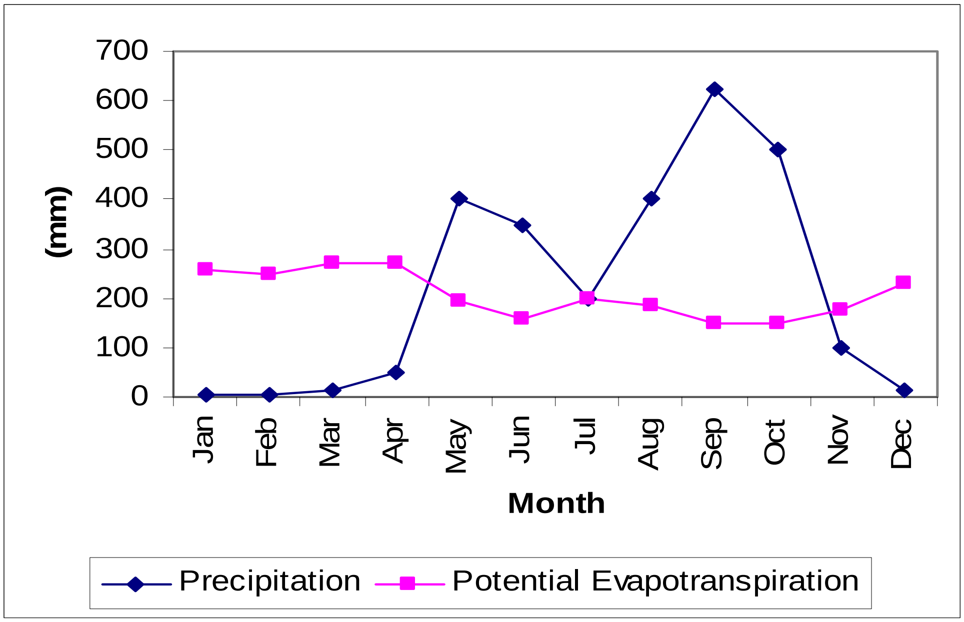

Figure 8. Monthly mean precipitation (1978-1988) and potential evapotranspiration (Mayorga 1989 and COHDEFOR 1994).

Rainfall in the area has the potential to be variable from year to year. During my time in El Corpus, I witnessed two rainy seasons; the first, in 2004, was disappointing to many and catastrophic to some as crops failed and emergency food aid had to be distributed in some municipalities. The second rainy season in 2005 was much wetter and resulted in some complaints that the over-abundance of rain was ruining certain vegetable crops. At Los Espabeles, in the adjacent municipality of Namasigue, Thurow and Smith (1998) measured rainfall amount, duration and intensity over a five-year period between 1993 and 1997. During that time, total annual rainfall ranged from 1297 mm to 2795 mm, a difference of over 100%. Such variability has the potential to be damaging to the livelihood of small farmers, who may already be producing at or below subsistence levels due to small land holdings, poor soils, or lack of access to credit which precludes inputs such as fertilizer.

Geology and Soils

Although today Honduras has no active volcanoes, Central America in general is volcanically active. The parent material most prevalent throughout southern Honduras, and indeed, much of the country, is of volcanic origin. Referred to as the Padre Miguel group, it is comprised of sedimentary layers derived from volcanic rock and flows of basalt, andesite and rhyolite (Elvir 1974). This stratigraphic unit comprises the majority of the mountains south of the Choluteca River in the Choluteca department, and covers most of the *municipio* of El Corpus. The southwestern portion of El Corpus, however, including Cerro Guanacaure and the Agua Fría area, is characterized by intrusive tertiary and cretaceous rocks including granite, diorites and quartz (Mayorga 1989, Elvir 1974).

Original soil classification by the National Geographic Institute described the soils as Haplustalfs (Mayorga 1989), however this has been confirmed only in flatter areas (Thurow and Smith 1998). This would place them in the soil order Alfisols. Site-specific soil investigations later identified soils of the steeper mountain slopes in both Namasigue and El Corpus as belonging to the order Inceptisols. Specifically, soils were classified as fine-loam Typic Ustropepts (Zamorano 2004, Thurow and Smith 1998). At sites in Los Espabeles, Namasigue, topsoil depths of 7 cm to 31 cm, with means between 14 and 17 cm, were reported (Thurow and Smith 1998). Soil pits in El Corpus classified the soils specifically as Dystropepts in the Chinampa series (Zamorano 1994). Other soil pits excavated at the Santa Rosa Experimental Station, located where the lower slopes of Guanacaure meet the Choluteca valley floor, confirmed the presence of Typic Ustropepts, as well as Entic Haplustolls (Mollisoll) at certain steep (65-75%) mountain footslopes (Hellin and Larrea 1997).

Forest Ecology

The lowland coastal plain of southern Honduras is generally covered by a combination of broadleaf trees and semi-arid scrub which is tolerant of the extreme drought brought on by the dry season. The dominant forest type in highland areas throughout the country is comprised of pine and oak. In the south the occasional pine begins to appear at 600 m in elevation, with pine (*Pinus oocarpa*) and oak (*Quercus spp*) being the predominant species beginning at approximately 800 m elevation.

The *municipio* of El Corpus is found at an elevation range between the lowland coastal plain and the pine-covered highlands. Tropical dry forest is found where the Choluteca Valley transitions into the foothills. Uphill from this transition zone is found the majority of land area encompassing the study area. The vegetation is classified as belonging to two forest types. These are *Tropical humid forest*, which ranges from the lower reaches of the watershed up to approximately 600m in elevation, and *Tropical semi-deciduous broad-leaved submontane forest*, which dominates up to the upper reaches of the watershed (Mayorga 1989, COHDEFOR 1994). It is important to note that the upper reaches of Cerro Guanacaure are covered in the broadleaf semi-deciduous forest type as well, and do not transition to the pine/oak system even though the elevation at the peak is just over 1000m. Major dominant and codominant tree species of the study area include Carreto (*Samanea saman*), Guanacaste (*Enterolobium ciclocarpus*), Guanacaste Blanco (*Albizzia caribea*), Laurel (*Cordia alliodora*) and Cedro Real (*Cedrela odorata*). Cedro Espino (*Bombacopsis quinata*), prized for its straight wood, is named for the spines along its trunk and branches (*espino* means spine or thorn) and is perceived to be in decline in the area due to high-grade harvesting (Figure 9). Trees visually striking for their size include the Guanacaste and the Ceiba (*Ceiba pentandra)* often found along creek beds or in humid microclimates. Although these trees can be over a meter in diameter, they are the exception; the forest found in El Corpus is considered secondary forest, and few individual trees approaching that size can be seen.

Figure 9. The aptly-named Cedro Espino (*Bombacopsis quinata*).

The area's forests reflect adaptations to the climatological conditions. The climatic extremes greatly influence the forest type. Many tree species are deciduous, shedding leaves during the dry season and flushing again immediately before or during the onset of the rainy season. Flowering occurs during the dry season for many species, which then disperse seeds at the onset of the rains. The tree species found in the lower elevations and on the valley floor near the city of Choluteca are more likely to be deciduous, while the higher elevations remain green with foliage later in the dry season (Figure 10).

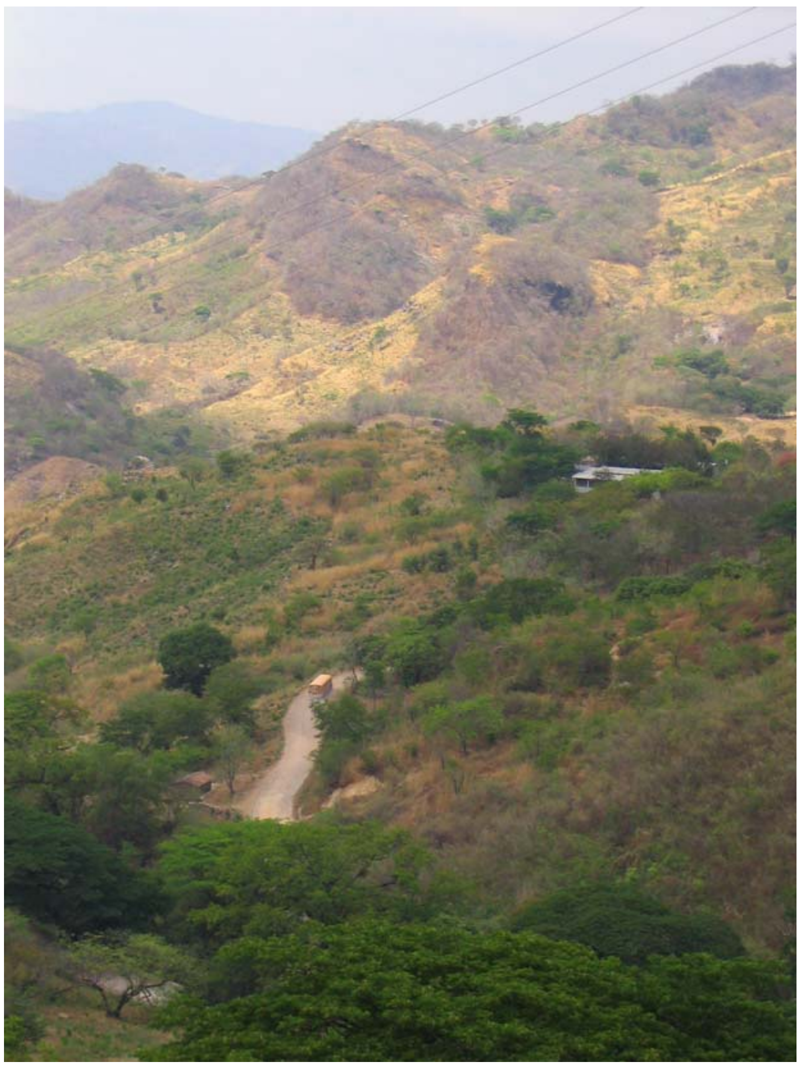

Figure 10. Evergreen and deciduous (far hillside) trees in mid-March.

From a distance, the upper reaches of Cerro Guanacaure (elevation 1007 m) remain the greenest portion of the mountain vista well into the late dry season months of

March and April. The adaptations are consistent throughout the Pacific coastal forests along the Central American coast. In Costa Rica’s Guanacaste Province, a region on the Pacific coast which receives annual rainfall amounts roughly similar to those of the Choluteca Valley (about 1800 mm), up to 75% of all trees are deciduous (Murphy and Lugo 1986). At the 2000 to 2500 mm rainfall found in cooler, higher-elevation Agua Fría, trees are able to retain their leaves for longer periods during the dry season.

Farming Systems

The basic traditional smallholder farming system in the south is a shifting cultivation system, in which land is alternately used for planting basic grains or left fallow for a period to restore soil fertility. The basic grains in the area include the traditional staple maize (*Zea ma*ys L.), as well as sorghum (*Sorghum bicolor* (L.) Moench), which has been widely adopted due to its drought-tolerance. Beans (*Phaseolus spp*.) and cowpeas (*Vigna spp*.) are also occasionally grown, but with less frequency than elsewhere in Honduras. It is estimated that together these basic grains account for 64% of the protein and 75% of the energy of household nutrition in southern Honduras (Thurow and Smith 1998). Traditionally, land was cultivated for three to six years, then as productivity declined, it was allowed to remain fallow and small native shrubs began to recolonize the parcel (Thurow and Smith 1998, DeWalt 1985). This fallow period was as long as fifteen to twenty years as recently as the 1950s, but today lasts only a few years or less, if at all, between plantings (Stonich and DeWalt 1996). Following the fallow period, the shrubby secondary forest on the parcel was cut, and either allowed to remain on the ground as natural mulch while crops were sown, or burned to maximize the amount of sunlight reaching the ground and to quickly return the stored plant nutrients to the soil. Fallow periods have decreased or been eliminated completely, however, as increased population pressure and alternative land uses, including allowing cattle to graze non-cultivated parcels, have changed the traditional cycle (Figure 11). In 1950, 14.9 percent of the land in the South was classified as fallow; in 1974 that amount had fallen to 5.6% (Boyer 1982).

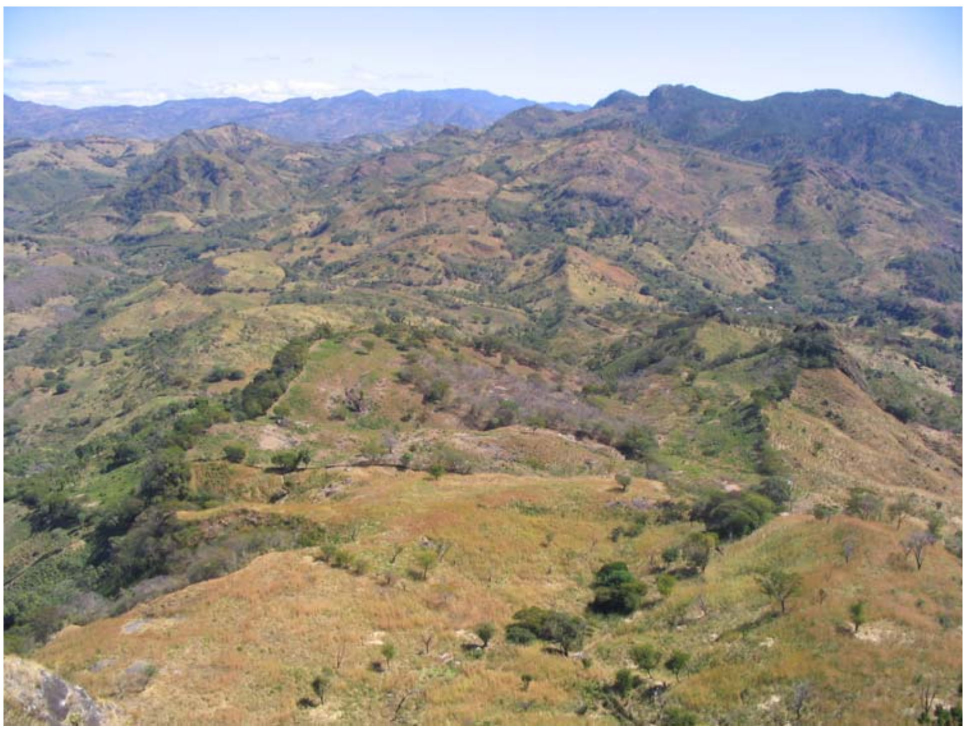

Figure 11. Dry season mosaic of post-harvest crop fields, fallow lands and pastures.

Semi-permanent crops are another common agricultural system. This category includes tree crops and coffee. Throughout Honduras, many families have fruit trees near their houses to provide shade and supplement the diet with vitamin-rich foods during certain times of the year. In the El Corpus area, the most common fruit trees grown include mango (*Mangifera indica*), mamon (*Melicoccus bijugatus*), orange and lime (*Citrus spp*.), bananas and plantains (*Musa spp*.), papaya (*Carica papaya*) and avocado

(*Persea americana*). Rarely will fruit trees themselves be an extensively planted crop, however the occasional banana and plantain patch could reach an acre or two in size. Bananas are often intercropped with coffee (*Coffea arabica*), especially when the land in question has less than full canopy closure of mature trees above a shade-tolerant coffee variety. Coffee production increased throughout the south as transportation linkages were improved and the market economy developed. In El Corpus, coffee begins to appear at about 450 m in elevation, although it is most common at elevations above 700 m in the Cerro Guanacaure area, where it becomes the dominant crop.

Cattle production has become a major land use in the South, both in the flat lowland valleys and increasingly in the highlands as well. The expansion of cattle production has reduced the amount of land left in forest. Between 1950 and 1974, pasture land expanded from 41.9% of the land in the South to 61.1%, while forest cover has decreased from 25.8 to 13.6% (Boyer 1982). The conversion of forest to pasture has its roots in historical events, including consolidation of land holdings by a few rich landholders, smaller owners who wanted to demonstrate "use" of land in times of agrarian land reform, and improvements in transportation allowing access to markets (DeWalt 1985, Boyer 1982). This trend has been reflected throughout the study area. For example, an increase of 31.8% in the amount of grazing land in the immediate area of Cerro Guanacaure in El Corpus was reported by Mayorga (1988) in the eight years prior to his study in 1989.

Soil and land conservation

Soil and land improvement is an activity which relatively few farmers practice in the area despite the presence of regionally and internationally financed NGOs promoting soil conservation (Figure 12). In the 1980s and 1990s, USAID-financed projects promoted various techniques. These included mulching, in which no grazing or burning is allowed and crop residues are chopped and left on the field immediately prior to planting; construction of rock wall barriers to retain soil; and the use of soil-retaining plants such as Vetiver grass barriers (Figure 13). The method of extension initially paid farmers to construct rock walls through a food-for-work program under the Natural Resources Management Project (NRMP). Later, the program converted to a teach-and-visit methodology under the Land Use and Productivity Enhancement (LUPE) project (Thurow *et al.* 2004). The results of the project were still evident during my time in the area, as various farmers showed me rock walls and grass strips on steeply sloping fields.

The effect of these technologies on soil quality, moisture availability and crop production has been studied extensively in southern Honduras (Hellin and Larrea 1997, Toness, Thurow and Sierra 1998, Thompson 1992). Studies consistently found that the technologies were cost-effective and improved land quality in measurable ways, including reduced erosion, higher soil moisture availability, increased crop yields, and reduced landslide and sloughing occurrence.

Many farmers readily acknowledged that hillside fields with these technologies were “better” than those without them. Yet adoption of some of these technologies in the region has slowed since the termination of the NRMP and LUPE projects. The most obvious barrier to increased adoption of these technologies is the associated cost in terms of labor investment. Those with the least to spare in terms of labor or economic resources are often those with the least amount of land in production, and although they stand to benefit, they do not commit to making the initial investment. In fact, those with access to the smallest amount of land are *least* likely to engage in land conserving practices (DeWalt and Stonich 1999).

Figure 12. Newly planted crops on eroded and gullied hillside (left); steeply sloping burned pastures adjacent to the town of El Corpus (right).


Figure 13. Live grass barriers installed to reduce erosion on steep slopes in the Guanacaure protected area.

The most commonly adopted technology was mulching, which also had the lowest associated cost in terms of labor. A critical component of mulching is the elimination of fire and grazing on the selected parcels. In El Corpus, people's opinions regarding burning seemed to reflect widespread understanding of its harmful effects, and many residents and individual farmers would (quietly) criticize their neighbor's burning of fields. Although burning remains the predominant method of field preparation throughout the South, it is thought that its prevalence has been reduced in areas where the NRMP and LUPE projects worked (Santos *et al.* 2000).

These projects and others have attempted to improve people's livelihood while protecting the natural environment upon which those livelihoods depend. Throughout El

Corpus, land owners are struggling to provide an income for themselves and their families using a limited set of resources. Their actions, both individually and collectively, impact the natural resources upon which the country depends. Water resources are especially scarce in the Honduran South, and upstream landowners directly affect the quality and quantity of water available to downstream users. The collective environmental conscience of Hondurans rests on a few key ideas; one is that water availability is a critical issue which continues to affect both urban and rural communities throughout the country. During my time in Choluteca, an area with a pronounced dry season, I became interested in issues of water quantity and quality. The next chapter will outline the methods I developed to examine surface water in El Corpus.

Chapter 4: Methods and Sample Sites

Río Calderas Watershed

The Río Calderas is a third order stream draining the area around the municipal capital of El Corpus ($87^{o}2'00''$ W, $13^{o}17'16''$ N). Its tributaries originate at elevations up to 900 m and are formed by the waters of natural mountain springs. The watershed comprises an area of approximately 3300 ha. Upon leaving El Corpus at the foothills, it enters the *municipio* of Yusguare and becomes known as the Río Sampile (Figure 14).

Figure 14. The Río Calderas where it enters the Choluteca valley.

Within the watershed of the Río Calderas, two *quebradas*, or streams, were selected for more intensive analysis. These are the Quebrada San Juan and Quebrada El Sabroso (Fold out map). I chose these streams for several reasons. They are easily accessible from the town of El Corpus, a primary consideration when planning regular observation intervals (Kunkle *et al*. 1987). The watershed of each has been visibly impacted by human activity, through village construction, agricultural production and mining activities. Many houses outside the villages are sited near *quebradas* to take advantage of the water supply. Although the urban centers of El Corpus, San Juan Arriba and San Juan Abajo have potable water systems which bring water to many houses, in outlying areas there are many homes not served by the system, often forcing residents to obtain water from a stream. Even in areas served by water systems, some individual families can not afford the connection, maintenance or monthly fees associated with the municipal water system. I observed many people in these watersheds bringing stream water back to the house for domestic use; some families also supplement their in-home water supplies by using river water for bathing and washing laundry.

Sample Sites

Sample sites were chosen based on their location within the stream network, accessibility for sampling, type of upstream land use and potential point-source impacts on water quality (Kunkle *et al*. 1987, Campbell and Wildberger 1992, Canter 1985). Preliminary sites were considered along the Río Sampile, Río Calderas and upstream tributaries throughout my first year in El Corpus. Once the research goals were refined and points had been evaluated for accessibility, a total of eleven points were chosen for regular examination (Figure 15 and Fold out map). Three points (**Ca, Cb**, and **Cc**) were located along the Río Calderas; one each above and below the confluence of Quebrada El Sabroso, and one below the confluence of the Quebrada San Juan. Care was taken at sites **Ca** and **Cb** to ensure site location was sufficiently downstream to ensure complete mixing of the tributary flows (Canter 1985). The remaining sample sites were distributed within the microwatersheds of the Q. San Juan and Q. El Sabroso.

Quebrada San Juan

The Quebrada San Juan originates in the southwestern portion of the *municipio* of El Corpus, in secondary broadleaf forest near the communities of San Juan Arriba and Agua Fría. The headwaters springs are found within the Cerro Guanacaure Multiple Use Area. The area surrounding the *aldeas* of Agua Fría and San Juan Arriba is covered with secondary forest, with coffee plantations under shade as the predominant land use at higher elevations. There is one small-scale gold mine located in the middle San Juan watershed, a mercury-amalgam operation which processes crushed rock ore. Farther downstream, smallholder parcels of corn, sorghum, and cattle pasture become more frequent. The Q. San Juan then passes through the *aldea* of San Juan Abajo before joining with the Río Calderas.

There were five sample sites located inside the Q. San Juan watershed. Site **Ja** was located upstream of confluence of the Q. San Juan with the Río Calderas, just below the town of San Juan Abajo. Site **Jb** was located along a tributary of the Q. San Juan which drains the town of El Corpus and the area immediately adjacent. Wastewater from the El Corpus *aguas negras* system drained into this tributary. Site **Jc** was located on the Q. San Juan, immediately above the town of San Juan Abajo.

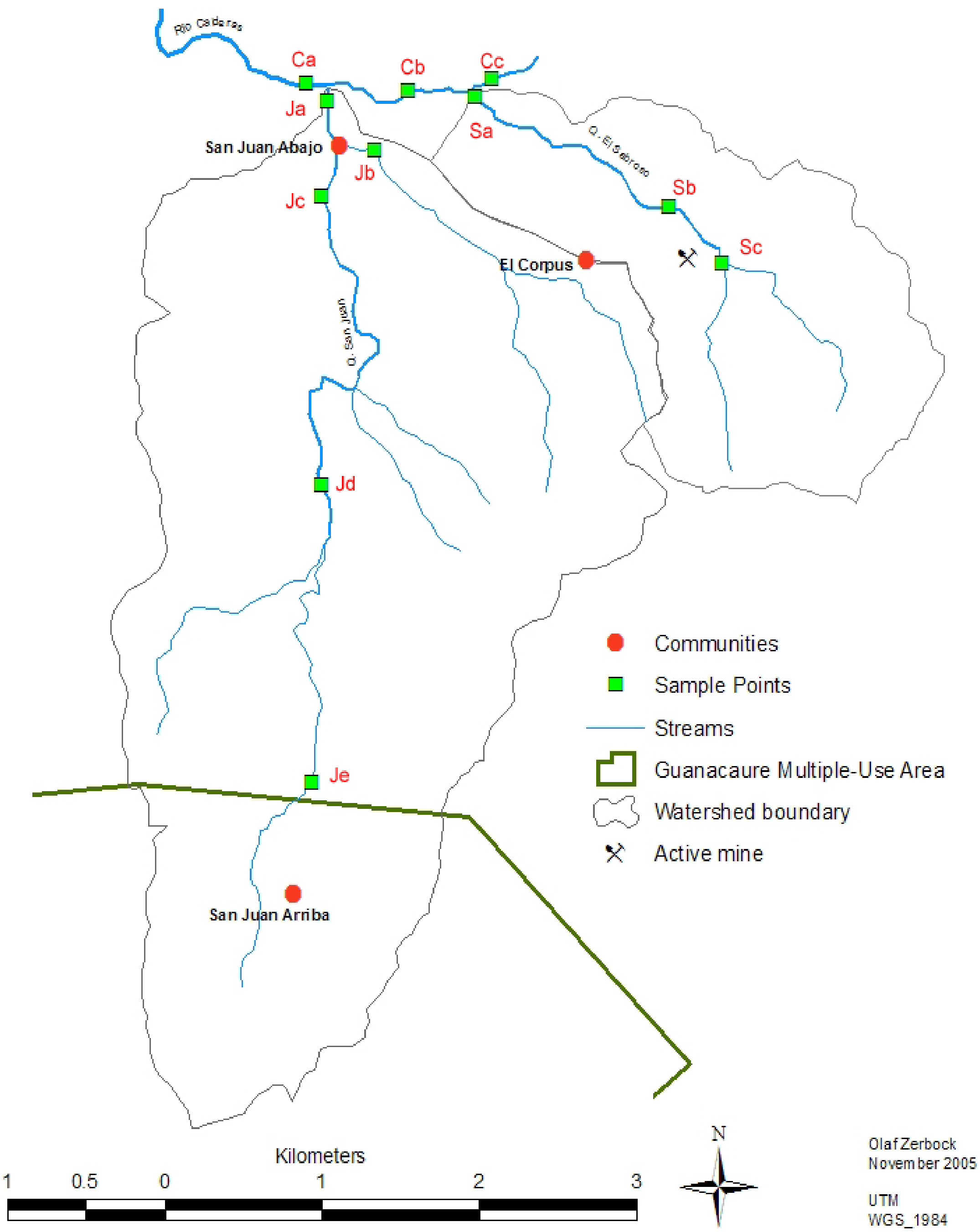

Figure 15. Locations of sample points along the San Juan and El Sabroso watersheds.

Approximately 1.5 km upstream was site **Jd** (Figure 16), where surrounding hillsides slope steeply through a variety of cattle pastures and agricultural crops. The farthest upstream on the Q. San Juan was site **Je**, located just below the boundary of the Cerro Guanacaure Multiple-Use Area. The surrounding area is more heavily forested than areas downstream, with much of the land planted in coffee under shade.

Figure 16. Site *Jd*, on the Quebrada San Juan, in early November.

Quebrada El Sabroso

The Quebrada El Sabroso originates to the east of the community of El Corpus, in the transitional zone between broadleaf and pine forest types. The stream descends through land alternately forested and cultivated. This drainage is also the location of several current and former gold mining operations, including the newly expanded Mayan Gold mine operating on the “Clavo Rico” gold trend, the original gold vein which has been worked throughout the history of El Corpus. The mine removes ore from tunnels dug into the hillside, and extracts gold using a cyanide heap-leach process. The Q. El Sabroso flows past several smaller aggregations of houses before joining the Río Calderas upstream of its junction with the Q. San Juan.

Along the Q. El Sabroso, three individual sites were examined. Farthest upstream was site **Sc**, located at the confluence of two feeder streams. Downstream, site **Sb** was located where the *quebrada* crosses a road leading from El Corpus to *aldeas* farther east (Figure 17). This site was chosen because it is downstream of the active gold mine property. The third site, **Sa**, was located just above the stream’s confluence with the Río Calderas and downstream of the town of El Corpus.

Figure 17. Streamside erosion and low flow conditions near point *Sb* on the Quebrada El Sabroso.

Timing

Although some sites had been examined earlier, sampling began in earnest in early February 2005. Originally it was planned to take measurements at each sample point every two weeks. Measuring at eleven sites in two microwatersheds was a time consuming endeavor, however, and I determined that examining each point approximately once every three weeks was a more practical goal. Certain groups of points were often sampled on the same day due to their close proximity to each other; for example the points near the confluence of the Q. San Juan with the Río Calderas were usually examined together one day, while the Q. El Sabroso confluence points were examined another. For practical reasons it was impossible to measure all the points on one stream in the same day. Care was taken however to visit sites at the same time where a before-and-after relationship was examined; for example points **Sc** and **Sb** (upstream and downstream of the mine property, respectively) were always examined at the same time to examine the effect of the mine effluent.

The immediate effect of rainfall was also taken into account when determining exact sampling days and times. Measurements were taken almost exclusively in the morning hours before 10 a.m. to avoid rainfall, which was more prevalent in the afternoons and evenings. During the rainy season an attempt was made to avoid sampling on mornings immediately after an overnight rain event, to reduce the possibility that recent precipitation could be the sole cause of a change in a particular variable. One exception to this rule was made however, when sampling was performed in the morning immediately after a torrential overnight rainfall associated with a Pacific tropical storm event. This was done in order to take at least one set of measurements at what could possibly have been the highest flow event of the study period.

Stream water variables

Flow

Measurements to estimate stream water flow (discharge) were taken at all sample sites at the time of measurement. The equation of continuity gives the discharge of a channel (Ward and Trimble 2004):

$$\boldsymbol{q = va}$$

where $\boldsymbol{q}$ is the discharge in cubic meters per second, $\boldsymbol{a}$ is the cross-sectional area of the stream, and $\boldsymbol{v}$ is the average velocity of the flow.

Cross sectional area and velocity were measured by selecting a relatively straight and even-flowing stretch of stream close to the sample point. A cross-section of the stream's flow was recorded by measuring the width of the stream using a tape measure strung perpendicular to the stream flow. Depth measurements were then taken at regular intervals along the tape measure and used to construct the cross-sectional profile. The velocity of the water was measured using a floating object, a small piece of wood, which was timed as it traveled a measured distance on the stream. Time required to travel the distance was recorded five times, and the average time was then used in subsequent flow calculations (Dunne and Leopold 1978).

pH

The pH of a given sample refers to a sample's acidity, and is actually a measurement of the concentration and activity of the hydrogen ions present in a given sample. The examination of pH is a common practice in assessing water quality. Optimum for most freshwater fish and bottom-dwelling invertebrates is a pH between 6.5 and 9; outside of that range pH begins to have a toxic effect on aquatic life (Campbell and Wildberger 1992, Kunkle and Wilson 1984). The toxicity of other substances, such as metals, in water may be affected by the pH of water as well.

pH measurements in this study were taken using a handheld pH meter with built-in temperature sensor (Extech Instruments ExStik pH100), operated and calibrated according to the manufacturer's instructions. pH meters function by sensing the electric potential of the sample. This electrical potential is a function of the concentration of the hydrogen atoms in the sample liquid, and is measured by an epoxy or glass electrode at the point of contact with the sample. This measured electric potential is then compared to the potential of a reference electrode, and the difference is used by the meter to calculate the pH value of the sample. Measurements must be compensated for the effect of temperature on the activity of hydrogen ions in the sample.

The ExStik pH100 is a handheld pH meter which combines the reference electrode and the pH sensing electrode into a single unit, and incorporates a temperature sensor to automatically compensate measured values. At each sampling event, the pH meter was turned on and the sensor placed in the current for several minutes to allow the temperature reading to stabilize. Five measurements of pH were then recorded in different parts of the channel to ensure readings were representative of the sample point.

Conductivity and total dissolved solids

The conductivity, or specific electrical conductance, of water is another commonly used indicator of water quality (Kunkle and Wilson 1984). The conductivity of a water sample is an expression of its ability to carry an electrical current, and depends on the concentration, mobility and valence of ions in the sample and the sample temperature (APHA 1995). A common use of conductivity measurements is for the estimation of the amount of material suspended or dissolved in water, referred to as the water's total dissolved solids (TDS). The level of TDS naturally found in surface water varies depending on the type of geologic formation through which the water passes. Changes in the value of conductivity over time or between sample points on a connected water system can indicate the presence of inorganic pollutants in water. The most common pollutants affecting surface water include nitrates and phosphates in manure or sewage, and metals such as iron and manganese in mine runoff (Kunkle and Wilson 1984).

Measurements of conductivity in this study were conducted using a handheld conductivity meter with built-in temperature sensor (Extech Instruments ExStik EC400), operated and calibrated according to the manufacturer's instructions. Conductivity meters function by immersing a two-electron probe into a liquid sample. Voltage is applied between the electrodes, which are usually spaced one centimeter apart. The drop in voltage between the electrodes caused by the presence of sample liquid is used to calculate the conductivity of the sample. The EC400 is a handheld meter which incorporates the electrodes and a temperature sensor. The unit automatically compensates for the effect of temperature on the conductivity of the sample. Measurements of conductivity are reported in microsiemens per centimeter (μS/cm).

At each sampling event, the meter was turned on and the sensor placed in the current for several minutes to allow the temperature to stabilize. Five measurements of conductivity were then taken in different parts of the channel to ensure readings were representative of the sample point.

Total dissolved solids (TDS) data reported in the data set are derived values calculated by the ExStik EC400. In this case TDS values do not represent physical measurement of solids, rather the values are derived by multiplying the measured conductivity in microsiemens per centimeter by a constant (usually between 0.5 and 0.9) to obtain TDS (in mg/L). The constant used to obtain the reported values was 0.7, the default setting on the ExStik EC400. The conductivity measurements reported in the data set for each sampling event were not used to calculate the corresponding TDS values; rather the values reported for TDS in the data set represent new individual measurements obtained by the EC400 during sampling.

Turbidity

The relative clarity or cloudiness of water is referred to as turbidity. A given water sample which appears cloudy is referred to as more turbid than a clear sample. Turbidity is caused by suspended solid matter, which scatters incident light as it passes through the water. Common sources of turbidity in natural waters include sediment from erosion and the activity of microscopic plankton. Turbidity affects aquatic life by blocking sunlight needed by photosynthetic plants, and by raising the water temperature as suspended particles absorb additional heat from the sun. Suspended sediments can also transport nutrients and pollutants.

In this study, turbidity was measured using a portable turbidity meter (Oakton T-100), operated and calibrated according to the manufacturer’s instructions (Figure 18). The Oakton T-100 measures turbidity using the nephelometric method, which measures light scattered by particles in suspension at a 90 degree angle to the direction of incident light, and reports turbidity in Nephelometric Turbidity Units (NTU). This method is the preferred standard when analyzing samples of relatively low turbidity (APHA 1995). Samples were collected from the center of the stream channel using glass cuvettes. The turbidity of the samples was measured upon return from the field, with ten turbidity readings taken on each individual sample. Samples were manually agitated between readings in order to preclude artificially low readings due to sediment settling.


Figure 18. The Oakton T-100 conductivity meter.

Laboratory analyses

In addition to measurements performed on site, on several occasions water samples (grab samples) were also taken to a private water analysis laboratory in the city of Choluteca. The Aguas de Choluteca company is responsible for municipal water distribution in the city of Choluteca, and their laboratory was contracted to analyze water samples for this study. Analyses were performed by laboratory personnel in accordance with Honduran Health Ministry standard analysis methods (Government of Honduras 1995). Variables examined were total coliform bacteria, fecal coliform bacteria, pH, turbidity, conductivity, ammonia, nitrites, sulfates, aluminum, phosphates, total iron, manganese, hardness, and total dissolved solids. Grab samples were collected in containers and transported on ice.

Land use mapping

A general land-use map of the Q. San Juan and Q. El Sabroso watershed was also created. While the preferred method for classification and quantification of land use is with the use of remote sensing imagery, aerial photos and satellite imagery of sufficient detail and temporal relevance was unavailable. Instead, the map was based on personal field observations recorded using a 1:24000 topographical map and a handheld GPS unit. Land area was classified as belonging to six classes. Agricultural and forest areas were placed into one of five categories based on the relative amount of tree cover present, from lands planted in pasture or annual crops with almost no trees present, to areas covered by secondary growth forest. The sixth category was Urban, which was applied to the communities of El Corpus and San Juan Abajo. These areas were to a large extent covered by trees, yet were characterized by the higher concentration of roads and buildings, as well as people and livestock. The land use/land cover map generated for this study is not meant to be all-inclusive nor spatially exact, rather to provide a context in which to interpret possible changes in water quality observed at the sample sites.

Precipitation

Rainfall data were collected using a standard backyard plastic rain gauge in El Corpus. Readings were taken daily when possible; when I was out of town and daily reading was not possible, rainfall was allowed to collect in the gauge until my return. Total collected rainfall was then divided by the number of days of collection, and an average daily rainfall was recorded for the days missed. Weather observations, including rainfall measured with a rain gauge, were also taken and recorded near the community of Agua Fría by a local resident trained and equipped by a government-sponsored project operating in the area. In both cases reported precipitation measurements are not intended to be interpreted as scientifically authoritative; rather the intent was to provide a general precipitation context in which to examine stream flows over time.

Chapter 5: Data

In this section, I present an introduction to the data collected. Data obtained during the course of the study period was extensive; the actual data set recorded is larger than can be easily summarized. Three sources of data were used in analysis. Examinations of key water quality indicators were performed with field instruments throughout the study period; the complete data set can be found in Appendix 1. Water samples were taken for analysis by a private water quality laboratory; the complete data can be found in Appendix 2. Two inspection reports of an active gold mine located in El Corpus by the Honduran government agency responsible for mining oversight can be found in Appendix 3.

General trends associated with each water quality variable will be presented. Data quality and precision is discussed. For each variable examined with field instruments, a representative sample point will be used to illustrate the general trend associated with that variable over time during the sample period. Analysis of the data found will be discussed in Chapter 6.

pH

pH showed the least change over time at any given point of all the primary variables measured. Average values for pH across all points during the study period ranged from 7.08 to 8.88. Individual sample sites did show a variation in pH over time, but this variation was limited. The values obtained at site **Ja** are an example (Figure 19). At site **Ja**, average values for pH were taken on eight separate occasions (sampling events), and ranged from 7.82 to 8.21. Readings taken during a single sampling event showed little variation. The maximum range between highest and lowest individual readings of pH was 0.08. The standard error of individual readings within the same sampling event ranged from 0.01 to 0.02.

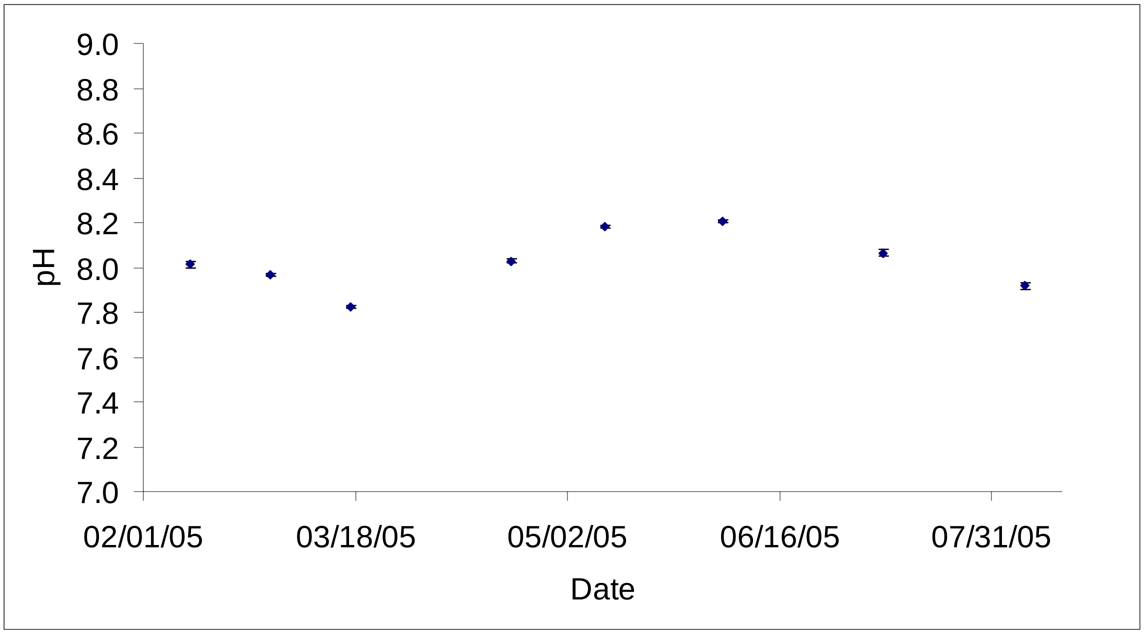

Figure 19. pH values obtained on eight occasions at site *Ja* on Quebrada San Juan. Error bars represent the standard error of individual readings.

Conductivity and total dissolved solids (TDS)

Conductivity showed more variation over time than did pH. Throughout the study period, conductivity ranged from 81.4 to 479.8 microsiemens per centimeter (μS/cm) across all sampling points. An example of the variation in conductivity measured at a single sample point over time can be illustrated by site **Sc** (Figure 20). At site **Sc**, conductivity readings were taken on eleven occasions. The values measured ranged from

126.4 to 385.4 μS/cm. Individual readings taken during each sampling event showed little variation. The maximum range between highest and lowest individual readings of conductivity was 8 μS/cm. Standard error of individual measurements ranged from 0.3 to 2.3 μS/cm.

Since TDS is derived from measured conductivity, the trends and error ranges of TDS measurements would mirror those of conductivity; hence TDS is not represented by a separate graph here.

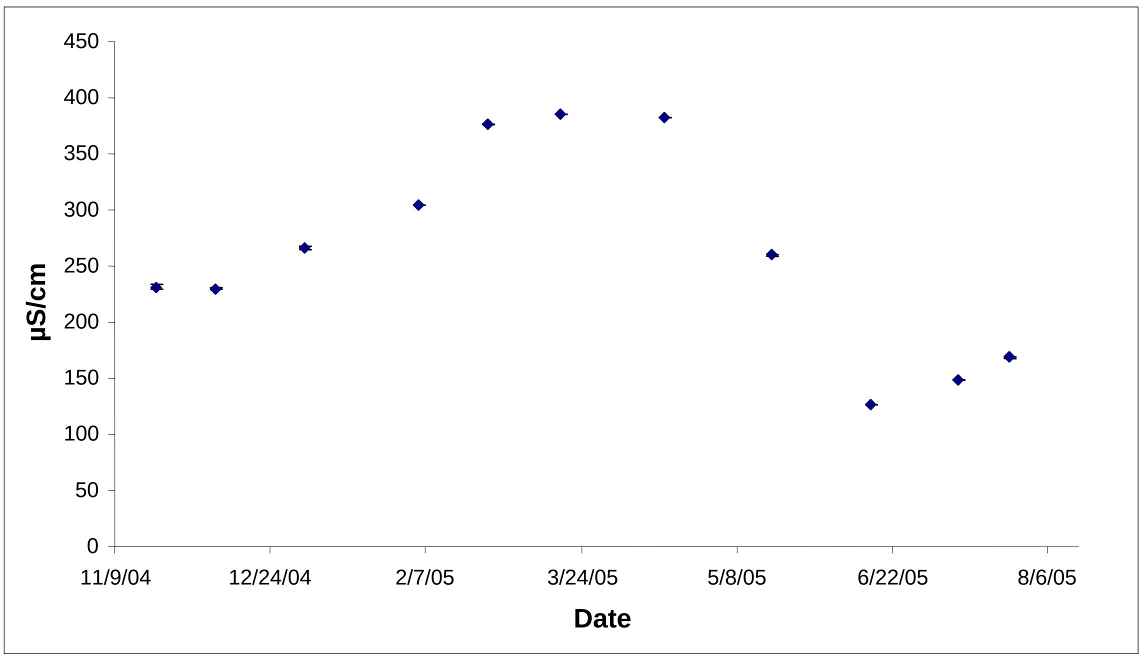

Figure 20. Conductivity measurements obtained on eleven occasions at site *Sc* on Quebrada El Sabroso. Error bars represent the standard error of individual readings.

The conductivity of surface water was also found to be variable across sample sites and time. This is not unexpected, as the conductivity of surface water is often affected by dilution; water flow information is usually needed in order to interpret conductivity measurements. The conductivity of water is dependent on the type and quantity of ions in the solution. Mineral-rich ground water is often relatively high in iron and other conductive ions, while surface runoff water is relatively mineral poor. During periods of low runoff, stream water may be entirely made up of ion-rich ground water and therefore exhibit higher conductivity. During periods of higher runoff, such as rainy periods or snowmelt, surface runoff serves to reduce the concentration of conductive ions in surface water (Kunkle and Wilson 1984). The conductivity dilution concept applies equally to natural and point-sources of conductive ions; in both cases increases in conductivity are a result of increases in the number of ions present and are affected by dilution in the same way. The result of the dilution effect means that in general terms, conductivity of surface water is expected to be higher during low-flow periods and decrease during high-runoff periods, as surface runoff dilutes the concentration of conductive ions. Although surface runoff may appear more polluted due to the visual effect of silt and other particles in suspension, chemically the flow may well be less polluted than clearer, pre-storm flow (Kunkle and Wilson 1984).

As expected, during periods of higher flow, conductivity was in fact lower than during periods of lower flow. The general relationship between conductivity and water flow during the study period is illustrated in Figure 21, and is similar to that found for other watersheds (Kunkle and Wilson 1984). The mathematical relationship between flow and conductivity in surface waters varies on a stream-by-stream basis, and can be calculated provided enough data points. It is usually negatively correlated and non-linear (Kunkle and Comer 1972).

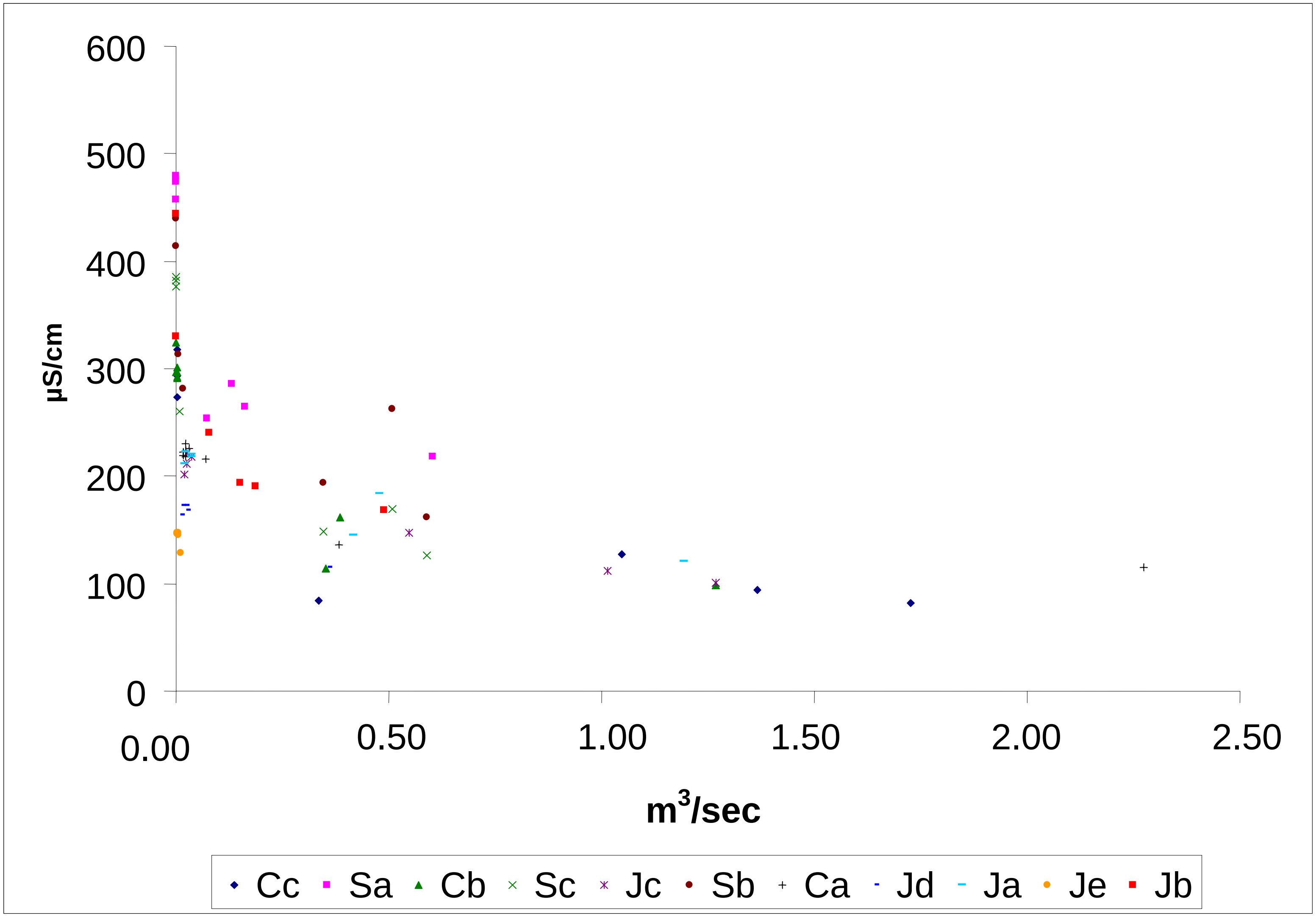

Figure 21. Flow and conductivity values by sample site across all sampling events.

Turbidity

Turbidity values obtained showed variation over time as well. Values obtained for turbidity ranged from 0.44 to 693 NTU across all sampling points and dates. Trends observed at site **Cc** (Figure 22) were similar to those exhibited at other points. At site **Cc**, turbidity was measured on eight occasions, and average turbidity values ranged from 0.34 to 13.9 NTU. The highest variation observed between individual turbidity readings on the same sample date was 5.2 NTU. Standard error of individual measurements ranged from 0.03 to 0.55 NTU.

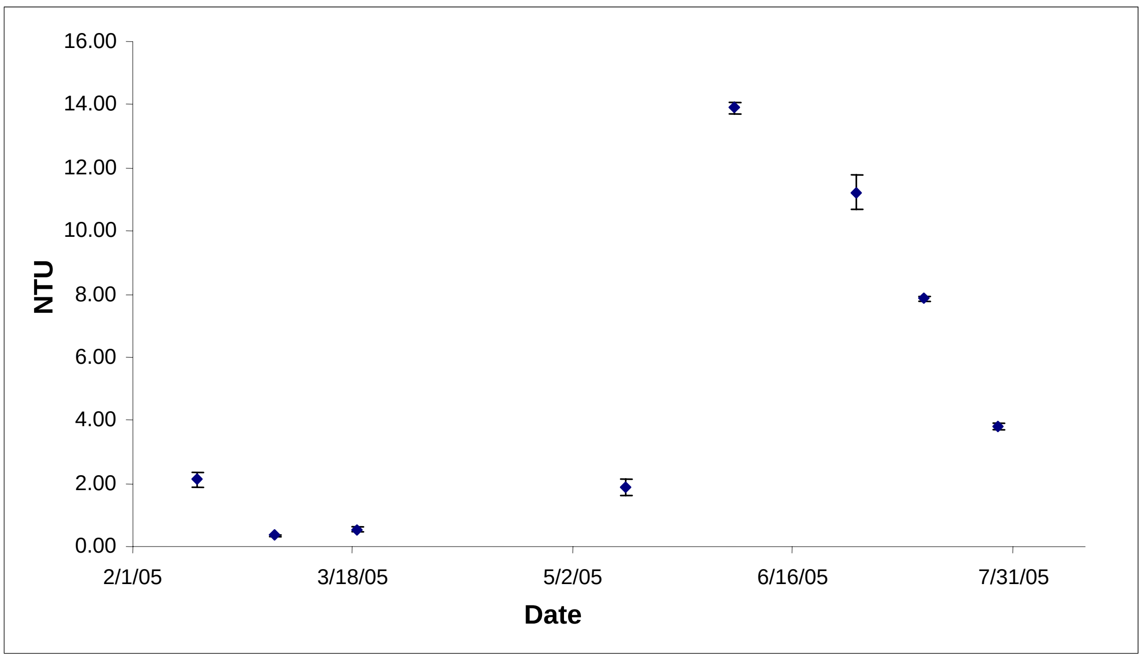

Figure 22. Turbidity measurements taken on eight occasions at site *Cc*. Error bars represent the standard error of individual readings.

Water turbidity varied not only at individual sites during the study period, but across all sample points and dates. In general terms, the lowest turbidity values were observed during the first half of the study period, when there was little or no rainfall.

Higher turbidity values were observed at higher flows (Figure 23), as surface runoff introduced suspended sediment from upstream catchment areas.

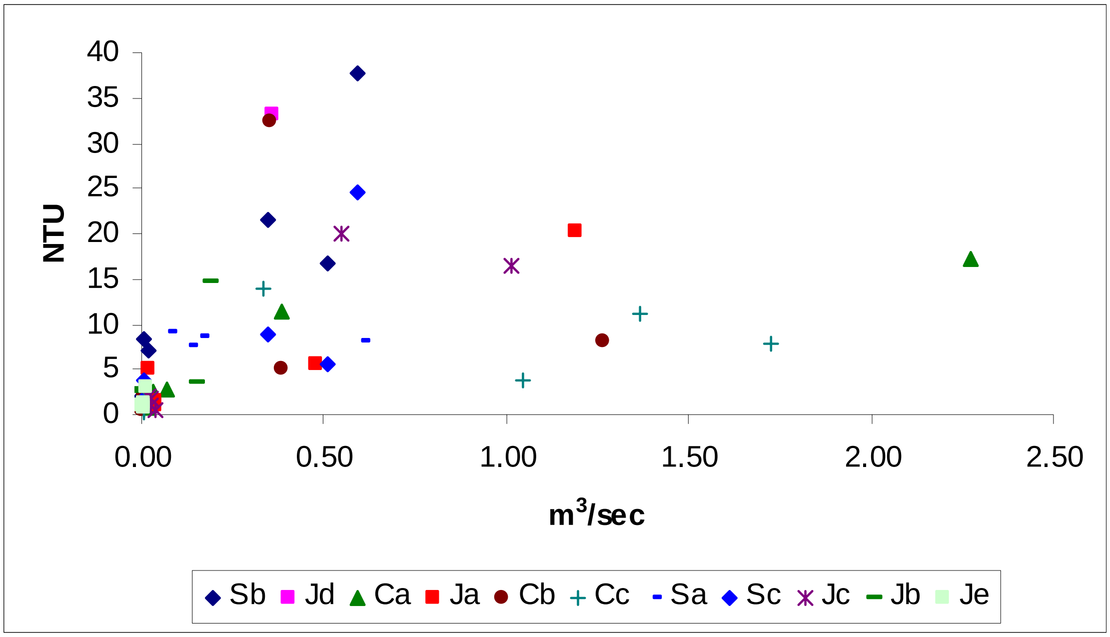

Figure 23. Flow and turbidity values by sample sites. Data collected at sites *Jb* and *Jc* on 5/20/05 are excluded.

Flow

This pattern of water flow rates during the study period is illustrated in Figure 24. During the first half of the study period, flows steadily decreased at most sites. At some sites, notably those on the Quebrada El Sabroso, above-ground water flow ceased during late March and April. Although occasional pools of standing water were observed in the stream bed, the flow was not measurable. Along the Quebrada San Juan, water flow never entirely ceased. The highest flow observed throughout the study period was 2.27 m^3/sec, observed at site **Ca** on the Río Calderas.

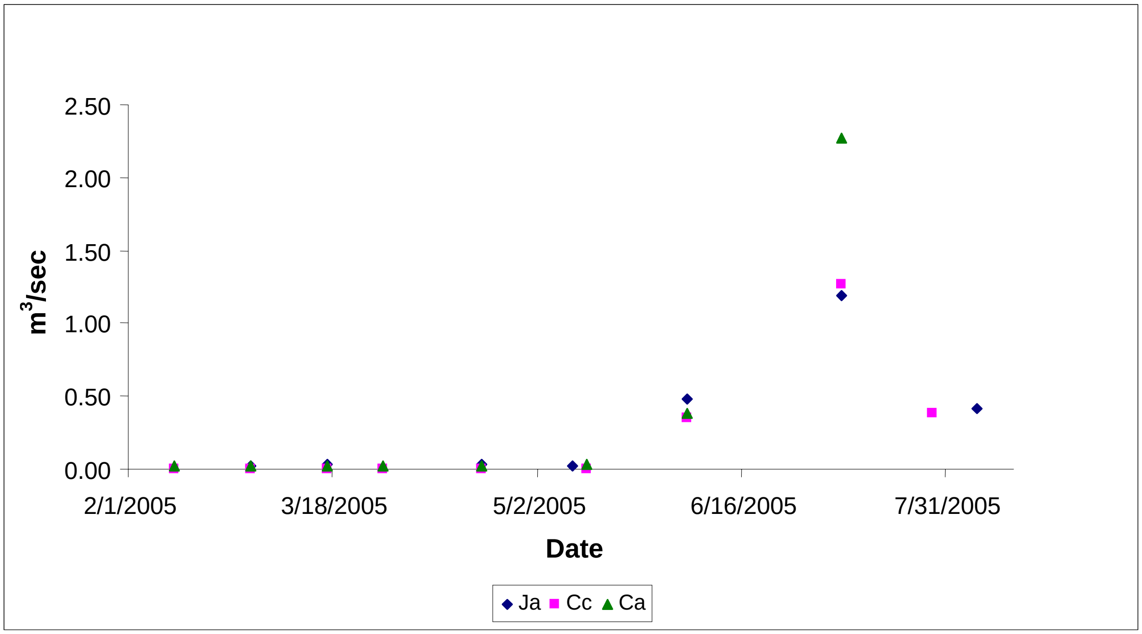

Figure 24. River flow measured at three sampling sites. Site *Cb* represents the upper R. Calderas, site *Ja* represents the Q. San Juan, and site *Ca* represents the R. Calderas downstream of the Q. San Juan confluence.

Precipitation

Precipitation measurements taken at El Corpus recorded 139.15 cm of rainfall between October 19, 2004 and August 3, 2005 (Figure 25). In Agua Fría, during the same period the total was 97.16 cm (Figure 26), however that figure does not include thirteen days of early rainy season measurements in late May and early June, for which data were missing. Precipitation data reflect the prevailing pattern of rainfall in El Corpus and southern Honduras (Figure 8, chapter 3).

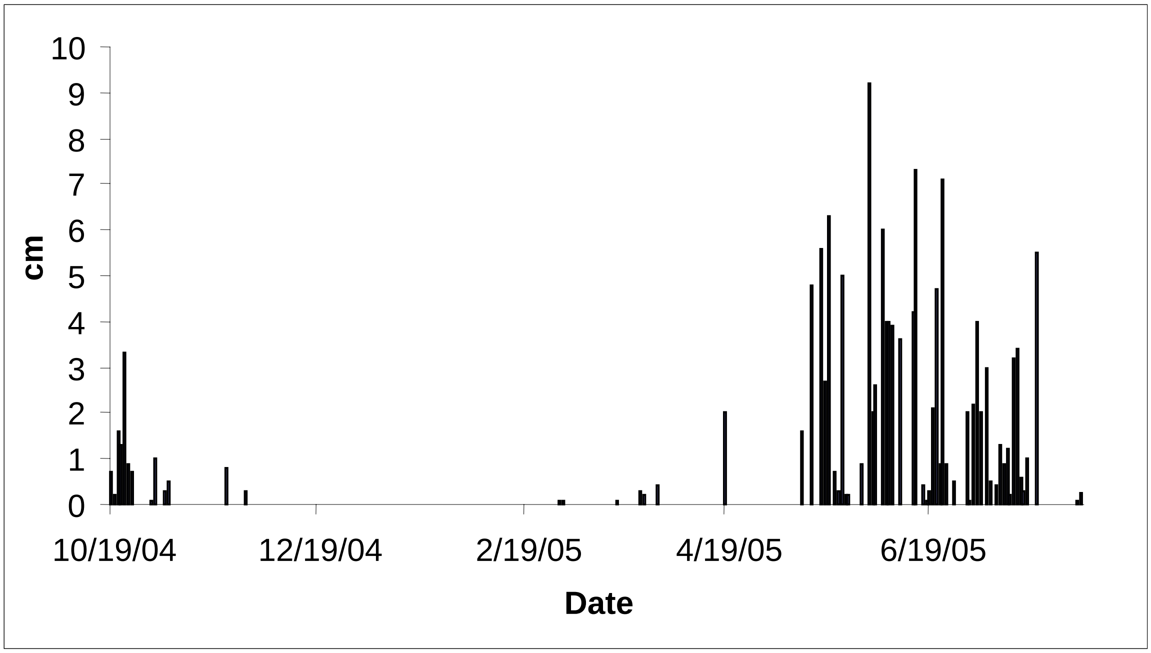

Figure 25. Daily precipitation measured at El Corpus from 10-19-04 to 8-03-05.

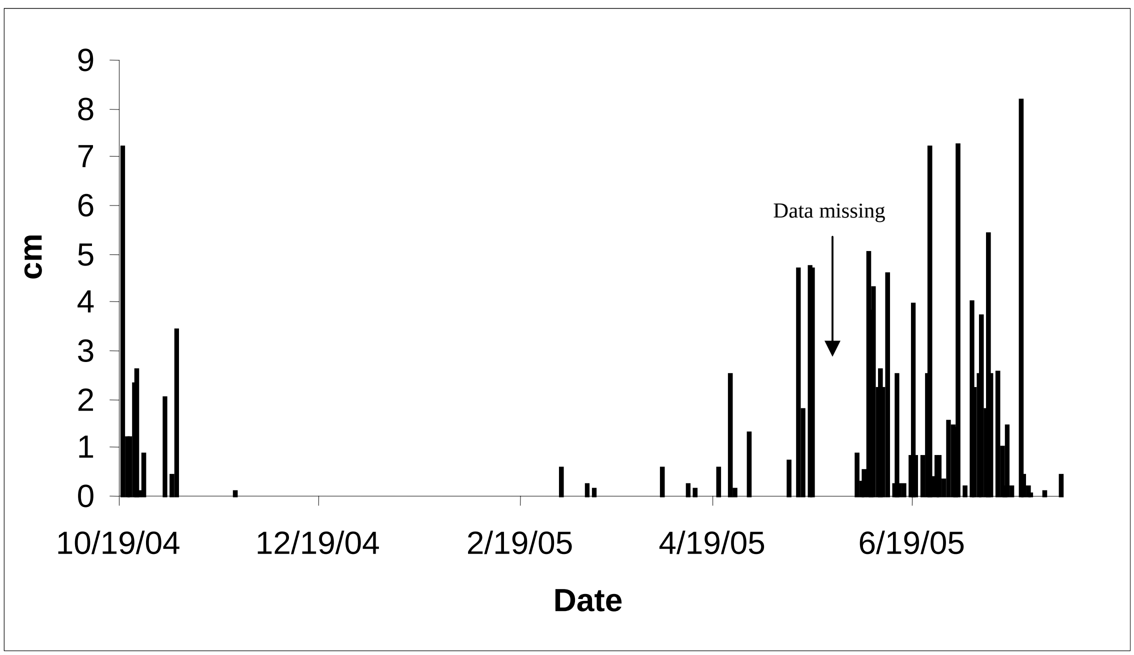

Figure 26. Daily precipitation measured at Agua Fría from 10-19-04 to 8-03-05. Data are missing for dates between 5-20-05 and 6-01-05.

Laboratory analyses

Samples were taken to the Aguas de Choluteca laboratory on eleven occasions, covering all eleven sample sites. Complete laboratory results are presented in Appendix 2. Samples were taken for analysis throughout the study period, including during both dry and rainy seasons. Direct and statistical comparisons between values obtained at different sample points are therefore not likely to be valid, since intermittent events such as rainfall between sampling occasions could be responsible for observed differences in individual variables. For all sites except **Sa**, **Cc**, and **Cb**, three separate sample containers were taken and carried to the laboratory simultaneously on the same date in order to obtain an indication of the precision of the laboratory measurements. Sites **Sa**, **Cc** and **Cb** were sampled on three separate occasions with one sample from each point taken on each date, in order to allow for more direct comparison between points free from the possible effects of intermittent rainfall between sampling events.

Statistical significance of differences in laboratory measurements cannot be calculated. Given time and equipment constraints, the laboratory was able to process a maximum of three individual samples at any one time. Time and logistical constraints in sample collection and transportation meant samples from most sites were analyzed only once during the study period. These constraints limited the number of values in the laboratory data set, and precluded meaningful statistical analysis of individual variables. The laboratory data do however provide a valuable context in which to view other measured values obtained during this study. Further, these results provide values against which to compare values measured with field instruments, since streamside values for conductivity and turbidity were obtained at the same time as samples were collected for transportation to the laboratory.

Field and laboratory data comparison

Although measurements were performed using different instruments, and are therefore not directly comparable, laboratory values for turbidity and especially conductivity showed general agreement with those obtained streamside. A comparison of field and laboratory values is presented in Table 2. Conductivity values showed greater agreement between the two sample sites than did turbidity. Differences in turbidity measures may be due to sample settlement or agitation inconsistencies.

		Conductivity (μS/cm)		Turbidity (NTU)	
Site	**Date**	**Field**	**Laboratory**	**Field**	**Laboratory**
Ja	5/10/05	223	213	4.94	4
Jb	4/18/05	444	456	2.43	3
Jc	4/20/05	219	208	0.55	2
Jd	6/10/05	115.2	110	33.19	19
Je	5/19/05	147.6	146	1.26	3
Ca	3/29/05	219	203	0.9	0
Cb	6/29/05	126.6	116	7.42	6
	7/13/05	99	95	8.21	7
	7/28/05	162.2	157	4.97	6
Cc	6/29/05	94.6	88	11.22	14
	7/13/05	81.4	86	7.86	5
	7/28/05	127.6	124	3.79	6
Sa	6/29/05	265	246	8.72	13
	7/13/05	218	201	8.09	6
	7/28/05	285	278	7.51	6
Sb	7/19/05	262	250	16.8	24
Sc	7/26/05	168.8	157	5.58	1

Table 2. Comparison of conductivity and turbidity values obtained by laboratory vs field measurements.

Land-Use Mapping

Land use was classified in both the Q. El Sabroso and Q. San Juan watersheds. The total watershed of the Q. El Sabroso was determined to be 404.86 ha, and that of the Q. San Juan was found to be 1291.35 ha. The amount of area in each land-use class is given in Table 3. Examples of each classification are presented in Figure 27. A map showing land use by class is presented in Figure 28 (and Fold out map).

	Q. El Sabroso		Q. San Juan	
Land use	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
Annual crops / pasture	103	25.43	272	21.05
Pasture with scattered trees	-	-	176	13.62
Trees with some crops / early secondary growth	96	23.70	309	23.92
Coffee under shade	-	-	265	20.51
Secondary forest	188	46.42	230	17.80
Urban	18	4.44	40	3.10
Total	**405**	100	**1292**	100

Table 3. Land use in the Q. El Sabroso and Q. San Juan watersheds. Percentages may not sum to 100 due to rounding.

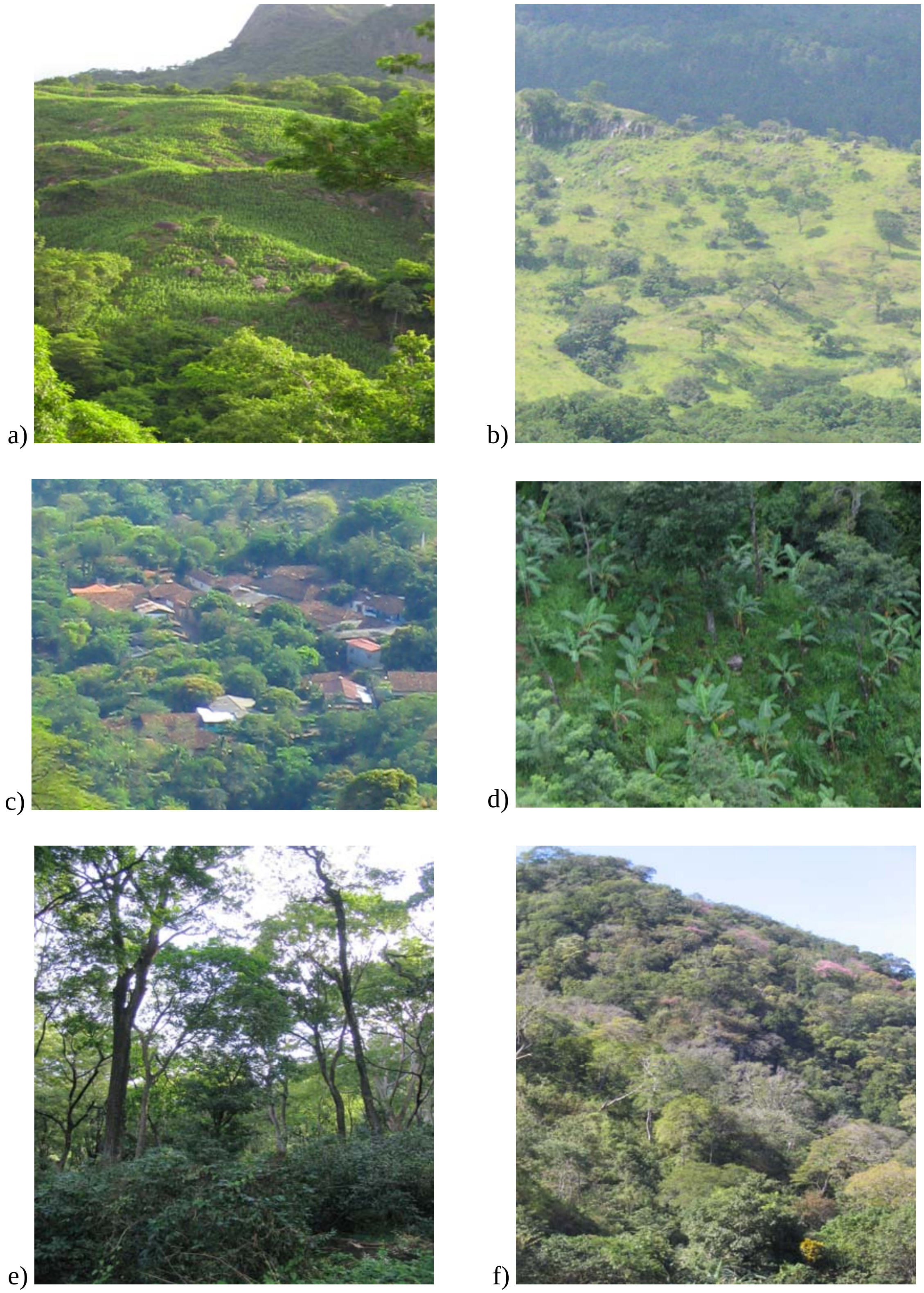

Figure 27. Land use classes: a) annual crops / pasture; b) pasture / crops with scattered trees; c) urban; d) trees with some crops or early secondary regeneration; e) coffee under shade; f) mature forest.

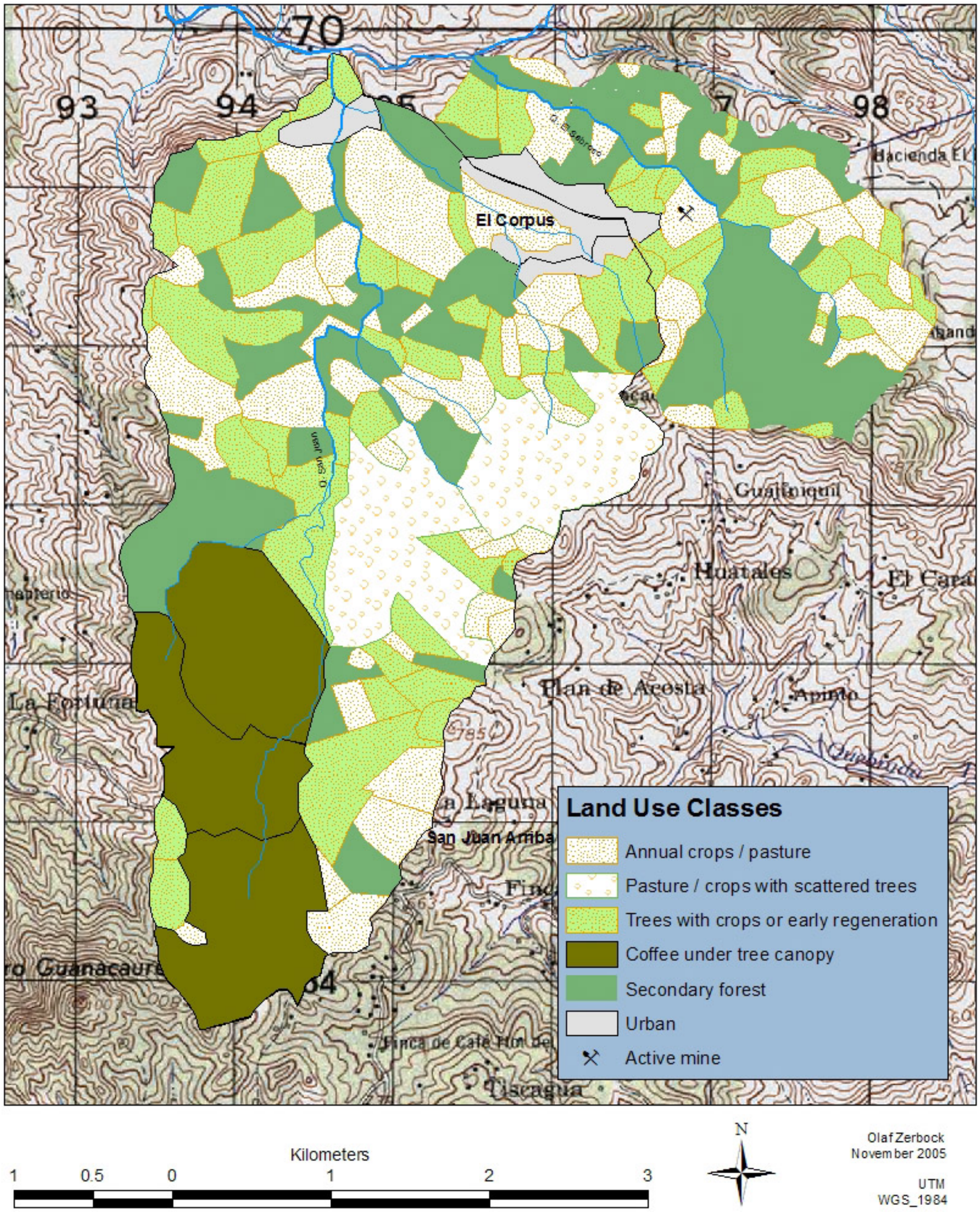

Figure 28. Land use in the Q. San Juan and Q. El Sabroso watersheds.

Chapter 6. Results and Discussion

The purpose of this study was to examine the relationship, if any, between land use and water quality in the Río Calderas watershed in southern Honduras. The preceding chapter illustrated the approach used to quantify the quality of surface water in the Q. San Juan and El Sabroso microwatersheds in El Corpus. Discussion in this section will describe observations of variables made at the various sample points and place them in the context of upstream land use. Observations will be discussed relative to other sample sites to highlight key differences between sample points and watersheds. Data obtained with field instruments will also be combined with results reported by the water laboratory in order to illustrate the impact of land use on water quality.

In the El Corpus watershed, the overview of land use presented earlier reveals that land can be grouped into three classes with some degree of overlap: urban, agricultural land, and forest. Assuming that the original, pre-settlement condition of lands in the watershed was forest, any increase in agriculture or human settlement would be expected to degrade the integrity of natural conditions. It would be expected that water quality as measured by certain indicators would be degraded as well. In this study, however, there is no ‘control’. All land in this watershed has been under human influence for hundreds of years; even headwaters springs in this area are surrounded by human activity. Truly ‘natural’ conditions are therefore impossible to estimate.

This section will however relate differences in key variables in order to demonstrate the degradation of water quality due to agriculture and urban areas. In addition, the point-source effects of gold mining will be shown to be of particular concern in the El Corpus watershed.

Agriculture: Quebrada San Juan

As subsistence farming is the tradition in Honduras, the watershed examined in El Corpus is largely agricultural. As illustrated in Table 2, Chapter 5, land-use classes in which tree cover is substantially reduced or completely removed (i.e. excluding coffee cultivation) cover more than half of the land area studied. In the El Sabroso watershed, 48% was classified as currently under annual production in crops or cattle or recently fallow; in the San Juan watershed the amount is 59%, with an additional 20% used for coffee under shade.

Water flow

In Honduras, I observed general agreement among farmers and agricultural and environmental scientists that reduced forest cover and increased agriculture in critical watersheds has reduced available surface water and stream flows. As forest cover is reduced, rainfall infiltration is reduced as well, leading to lower quantities of groundwater to supply dry season flows. The El Corpus area appears to be no exception to this pattern. Observations made during the study period in El Corpus show that in this watershed, surface water flows follow precipitation closely and dry season water availability is extremely limited. Examinations of water flow at individual sample sites showed water flow decreasing throughout the first half of the early study period, which fell during the latter half of the dry season. Surface flow in the Q. El Sabroso and upper Río Calderas ceased completely in places, although standing puddles of water and occasional short stretches of visibly moving water along the length of the streambed indicated continued minimal subsurface flow (Figure 29). The Q. San Juan was extremely low as well, although some surface movement was visible at all times.

Figure 29. Upper Río Calderas during the dry season. Although a trickle of water is visible at the waterfall (far back), flow is largely underground.

With the onset of regular rainfall in the month of May, stream flow began to increase until the first half of July; the highest recorded regular flows were observed at all sites between 6/5/05 and 7/13/05 (excluding the exceptional observations made at sites **Jb** and **Jc** during the tropical storm event of 5/20/05), at which time flow again began to decrease. This shows general agreement with rainfall data, which indicate that seven-day rain totals, averaged between Agua Fría and El Corpus, peaked on 7/11/05 (Figure 30).

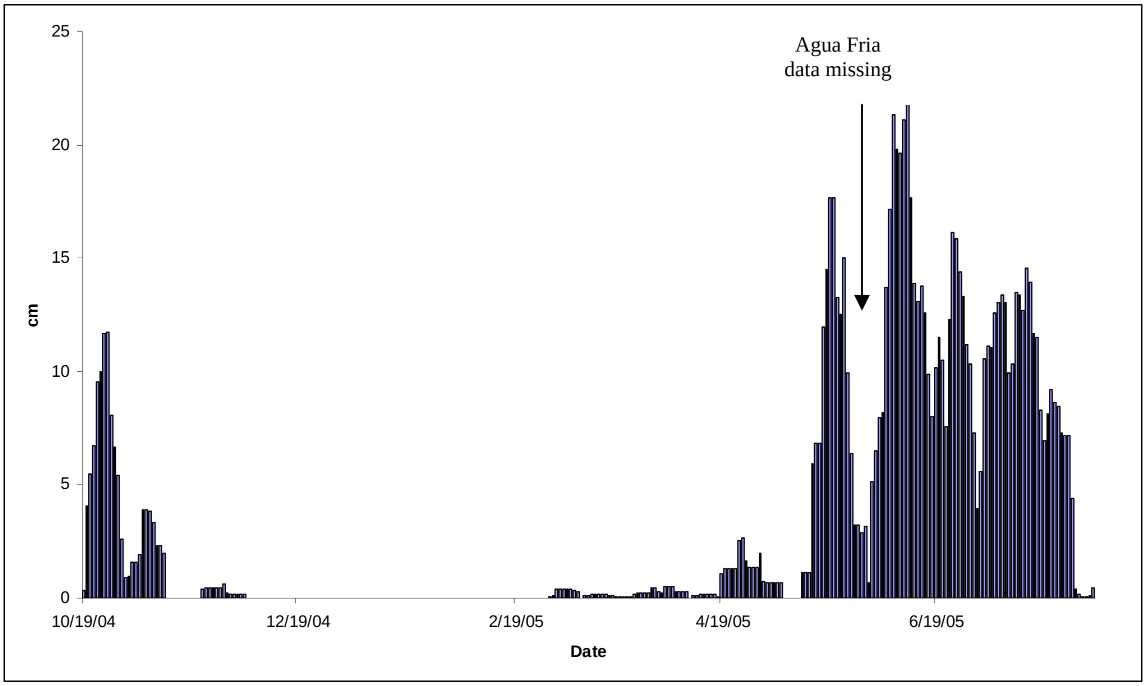

Figure 30. Cumulative rainfall for past seven days. Data for El Corpus and Agua Fría averaged. (Values during period 5/20/05 to 6/7/05 may be artificially low due to missing Agua Fría data during period 5/20/05 to 6/01/05).

A first observation of these low or non-existent low-season flows would seem to support the theory that deforestation and agriculture have had a significant effect on water flows. Water flowed year-round at point **Je**, which is located directly downstream of largely forested areas, suggesting that the more intact forests (including shaded coffee plantations) upstream of that sample point may be responsible for ensuring a consistent flow even during the driest parts of the year. The water sources which supply water flow upstream of **Je** are located well within the Guanacaure Multiple-Use Area, which was created specifically due to the area's importance in water production. Springs are located throughout the protected area, and even during the dry season its ability to maintain a healthy green color reflects higher availability of ground moisture. Tree cover is much more intact in this zone, and over a broader area, than elsewhere in the study area. Increased tree cover may be responsible for higher infiltration rates during rainy periods;

during the subsequent dry periods a higher quantity of groundwater would therefore be available to supply low-season flows (Bruijnzeel 1988).

Lacking historical data, however, it is impossible to ascertain whether this or any other of the streams consistently held water year-round prior to human alteration of the landscape. The scientific literature available on the topic of deforestation and seasonal low-flows in the tropics suggests a variety of factors are responsible for rainfall infiltration into the soil and resultant groundwater recharge, and that deforestation (or reforestation) does not always emerge as the single obvious parameter involved in the quantity of groundwater available to supply dry-season flows (Bruijnzeel 1988). Therefore, a more reliable indicator of the relationship between cleared agricultural lands and water quality may be to examine water turbidity.

Turbidity

The condition of cleared land, and the type of land-use thereafter instituted, may be a much more important factor in water quality and than the simple presence or absence of trees (Bruijnzeel 1988). In agricultural lands, a variety of factors affect the ability of rainfall to infiltrate the soil. Although the type of soil naturally present in a basin has an effect on infiltration rates, the manner in which the soil is prepared has an effect as well. The presence of organic matter in the soil, for example, has been shown to improve rainfall infiltration and water retention (Sanchez 1976). Conversion from forest to grazing or agriculture has been shown to significantly increase catchment sediment yield (Dunne 1979).

During the dry season, stream flows are comprised almost entirely of ground water from headwater springs. These flows are confined to the stream channel and their opportunity to pick up sediment is limited; during this period turbidity values can remain very low. During rain events, rain drops carry kinetic energy; the energy any particular drop carries is relative to its size and speed. The presence of vegetation breaks up raindrops into smaller droplets prior to impact with the ground, thus reducing their kinetic energy. The greater the amount of vegetative matter above the ground, the less raindrop surface area and energy is available to loosen soil particles and begin the erosive process.

Regardless of the amount of plant cover and organic matter on the ground, rain water begins to enter the stream system from surface runoff in the catchment during rain events. The less organic matter, such as dead leaves, plant residues, or roots present on or near the ground surface to slow the resultant runoff, the lower the rate of infiltration and the higher the erosion. Agricultural land prepared by incorporating organic matter, such as last season's crop residues, into the soil can greatly increase water infiltration. When infiltration rates are not sufficient to accommodate the quantity of rainfall, a condition known as saturation overland flow occurs. This happens as sub-soils are unable to absorb rainwater infiltrating into the topsoils and additional rain flows overland. These overland flows continue the process of picking up and transporting surface soil and sediment to stream systems. In this way erosion is readily visible in surface water, as eroded sediment makes its way into streams resulting in marked increases in turbidity. Turbidity can therefore be examined as an indicator of the extent and intensity of agricultural impact in the watershed.

In this study, water turbidity varied at individual sites during the study period. In general terms, the lowest turbidity values were observed during the first half of the study period, when there was little or no rainfall. Higher turbidity values were observed at higher flows (Figure 31), as surface runoff introduced suspended sediment from upstream catchment areas.

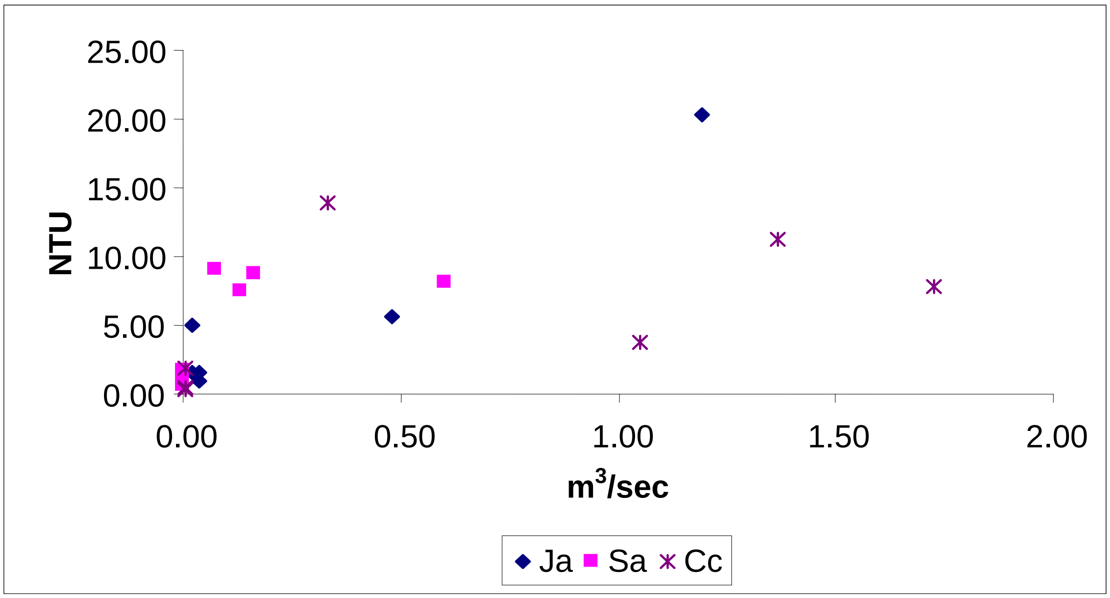

Figure 31. Water flow and turbidity at three sample sites. Site *Ja* is farthest downstream on the Q. San Juan, *Sa* is farthest downstream on the Q. El Sabroso, and *Cc* is on the R. Calderas prior to the confluence with El Sabroso.

Comparing turbidity between the streams suggests the Q. San Juan may be more subject to the impacts of erosion than the others. In Figure 31 (above), the farthest downstream points of the two microwatersheds (El Sabroso at Site **Sa** and San Juan at **Ja**) are compared, as well as point **Cc**, which serves as the farthest downstream point of the upper R. Calderas prior to its confluence with the other two streams. The highest turbidity value reflected in the graph is 20.3 NTU, recorded on the Q. San Juan at a flow rate of about 1.2 m^3/sec. El Sabroso turbidity values never reached half that value. Significantly lower maximum recorded flow rates on the Sabroso may be partly responsible. The flow rate at point **Cc** on the upper R. Calderas, however, reached recorded flow rates of 1.73 m^3/sec (1.44 times that of the Q. San Juan), while its turbidity value at that flow rate was less than half of that of the Q. San Juan.

It is important to note that, as described in Chapter 5, care was taken not to measure turbidity immediately after rainfall. During the rainy season, this study attempted, as much as possible, to examine 'background' turbidity at the sample sites to avoid reflecting the 'spikes' in turbidity which would be expected to immediately follow even light to moderate rainfall. Rainfall in the study area was usually not light to moderate, however, and followed more of a cloudburst pattern, and precipitation in El Corpus was often confined to short, high intensity afternoon thunderstorms.

Short periods of high rainfall intensities exacerbate the problem of erosion and sediment transport. Studies have shown that in some tropical catchments, rain events which occur once or twice a year carry the largest portion of sediment; one study in Kenya reported that catchments with more land use dedicated to agriculture or grazing than forest lose between 43 and 75 percent of their annual sediment yield in the highest one percent of flows (Dunne 1979). Erosivity indices, which combine rainfall intensity and energy, show that tropical regions often have highly "erosive" rain events. Erosive rain events can be defined as those having an intensity of at least 6.4 mm of rain in a fifteen minute period (Wischmeier and Smith 1978 as cited in El Swaify and Dangler 1982). These erosive rainfall events occur frequently in Honduras, where more than half of the country might experience 300 mm of rain in 24 hours (Hargreaves 1992 as cited in Rivera 2004). In the adjacent southern Honduran *municipio* of Namasigue, 50% of all rainfall events were found to have intensities greater than 20 mm/h, and 95% of all rainfall during a five-year study period was found to meet the above criteria for “erosive rain” (Thurow and Smith 1998). A preliminary model of rainfall erosivity for Honduras predicted very high erosivity indices for the study area relative to Honduras as a whole (Mikhailova et al 1997).

An excellent example of the effect of high-intensity rainfall on erosion and resultant turbidity was seen during the precipitation associated with Tropical Storm Adrian. Sampling was undertaken at two sites on the morning of 5/20/05, as the last bands of rain showers associated with the storm passed through the study area. More than 9 cm of rain had fallen on 5/18 and 5/19. An additional 6.3 cm fell overnight between 5/19 and 5/20, much of it falling between 5 and 8 am on 5/20. Turbidity measurements taken that morning between 10:00 and 11:30 am yielded the highest recorded values of the study period: 693 NTU at site **Jc**, and 146 NTU at site **Jb**. Excluding this sampling event, the highest turbidity values recorded at these two sites were 19.9 and 14.6 NTU, respectively, and a reading taken only ten days prior to the storm event at site **Jc** measured a turbidity value of only 1.8 NTU. The Corpus drainage has agricultural land, especially cattle pasture, upstream of sample site **Jb**, and this is reflected in its stream turbidity following the storm, which was ten times higher than the otherwise highest recorded value at this sample site. The much larger quantity of agricultural land use upstream of the sample point **Jc** clearly has the potential to contribute an enormous amount of eroded material to the stream flow during storm events, and the resulting water turbidity reflects this as well. The turbidity value measured at **Jc** was almost 35 times higher than the next highest value at this site.

Water quality degradation on the Q. San Juan

The land in the Q. San Juan watershed begins at its headwaters as a largely forested area. Since much of the upstream area is planted in coffee under shade trees, it is relatively vegetated. Scattered villages and rural homes are found throughout the area, although only a few residential clusters number more than 15-20 homes. The landscape rapidly changes from a predominantly forested headwaters area to agricultural fields in various stages of cultivation or fallow, eventually descending through the village of San Juan Abajo to its confluence with the Río Calderas. Water quality changed along the length of the Q. San Juan. A summary of key water quality indicators by sample sites is presented in Figure 32.

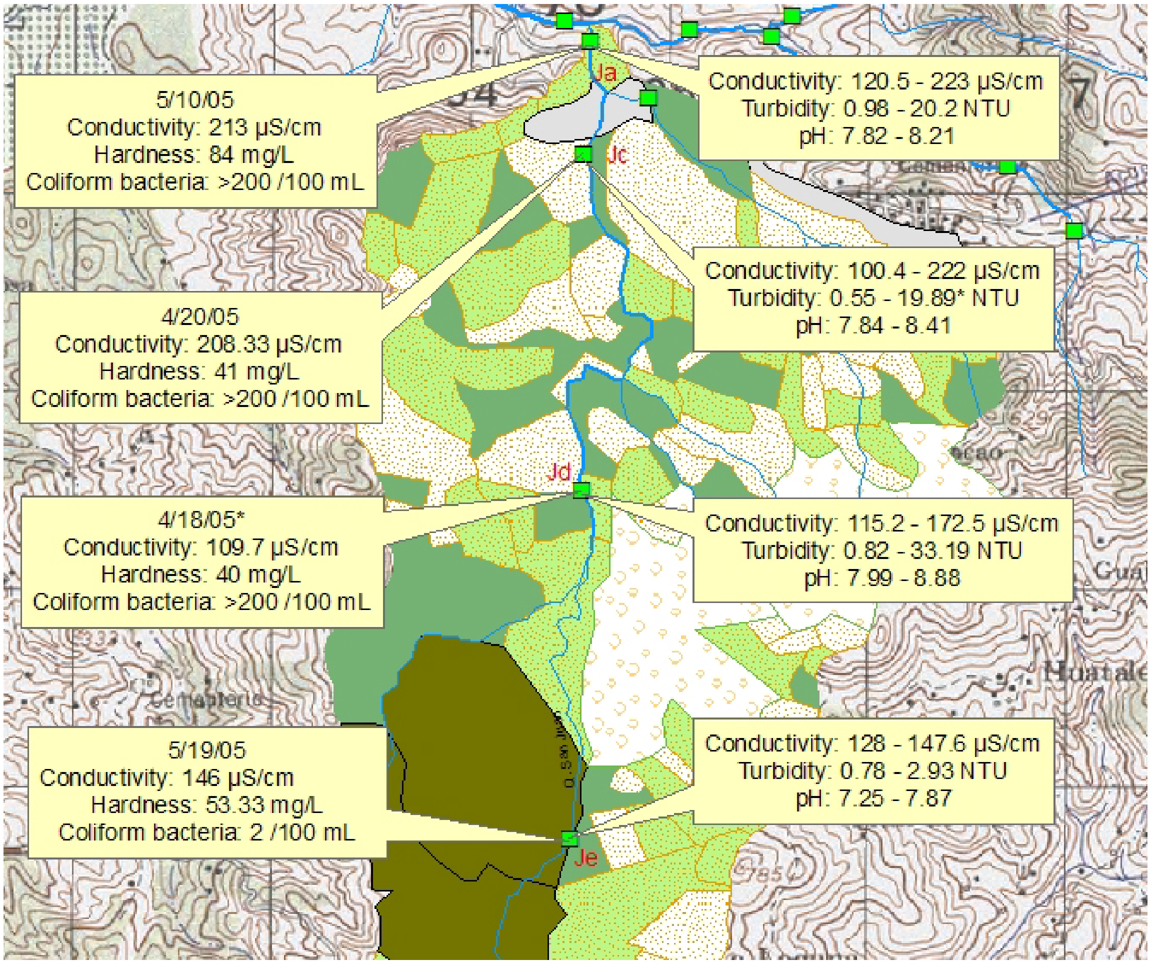

Figure 32. Water quality measurements for sample sites Jb and Jc. Conductivity, turbidity and pH field data value range during entire study period, with laboratory analysis values for dates indicated. (*) indicates sample taken closely following rain event.

Along the length of the Q. San Juan, a clear trend was identified with respect to conductivity. Values were lowest at site **Je**, farthest upstream, and conductivity increased downstream. Measurements taken with field instruments are presented in Figure 33. The steady increase in conductivity reflects continual increases in conductive ions in the stream water. While some of the increase may be due to natural weathering processes, continual agricultural cultivation along the hillsides and human activities such as bathing and washing laundry certainly contribute additional inputs reflected in the conductivity increase.

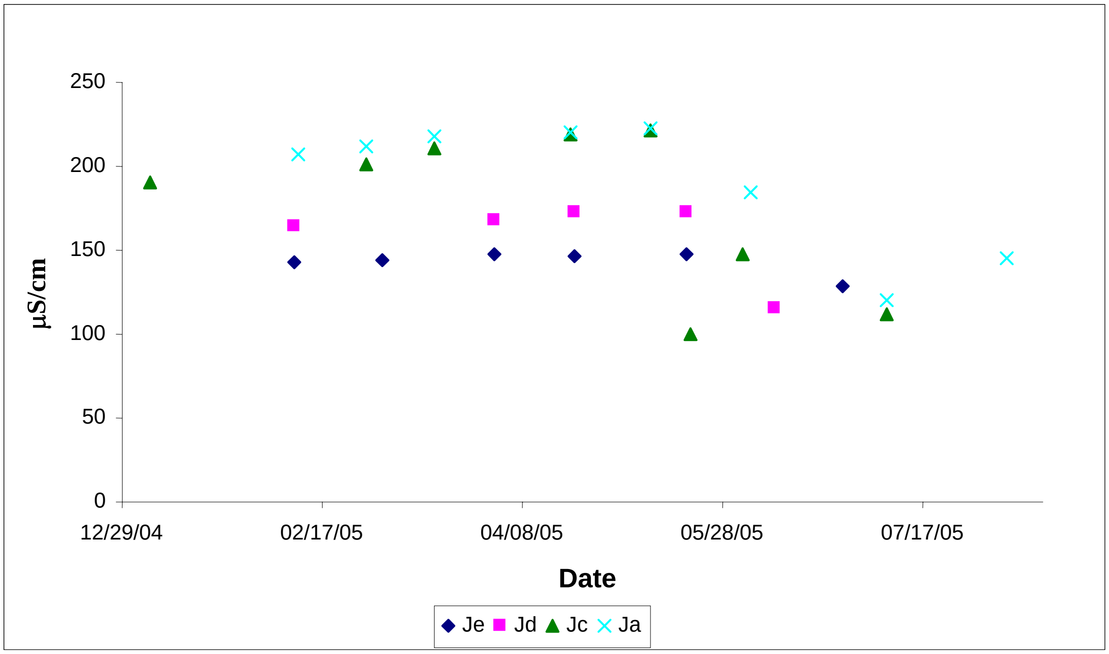

Figure 33. Conductivity values recorded at four sites on the Quebrada San Juan. Site *Je* was located the farthest upstream, with *Ja* immediately prior to the confluence with the Río Calderas.

Laboratory analyses were performed on samples from the four Q. San Juan samples sites, **Je**, **Jd**, **Jc**, and **Ja**, on one occasion each (site **Jb**, on the El Corpus town drainage, is treated separately below). Samples from the Q. San Juan reported nitrite values of 0.001 to 0.008 mg/L, phosphates ranged from 0.40 to 0.61 mg/L, and nitrate values from 1.0 to 1.8 mg/L; these variables showed no clear trends with respect to position on the stream.

Sulfate levels in the Q. San Juan, however, are higher than values reported for an adjacent watershed on the north slope of Cerro Guanacaure which passes through rural settlements and larger villages and is similar in geography and agricultural land use to the Q. San Juan (Mayorga 1989). In that study, the average sulfate level across all sample sites in the watershed was 4.58 mg/L. The highest value for any particular sample site was 9.25 mg/L. That site was located in the upper reaches of the watershed, immediately downstream of coffee plantations, similar in type to site **Je** in this study. The average sulfate value at **Je** (10.67 mg/L) was therefore close to that found in the previous study. Comparison between the two studies suggests that the Q. San Juan contains higher levels of sulfates than the adjacent Guanacaure watershed. Downstream of site **Je**, individual sulfate values reported for the Q. San Juan in this study ranged from 8 to 16 mg/L, except for a single, probably erroneous, measurement of 24 mg/L reported for site **Jc** (the other two simultaneous samples reported sulfate values of 9 and 11 mg/L). In general, Q. San Juan sulfate levels were slightly higher at the two downstream sample sites (**Jc** and **Ja**) than upstream at **Je**, possibly due to increased population density near the village of San Juan Abajo and the contribution of the El Corpus drainage. Direct comparisons are however difficult to make since samples were taken on different dates over a two month period.

Nitrates were also higher in the current study than the previous study. Mayorga (1989) reported an average nitrate value of 0.85 mg/L across all sample sites. In this study, value reported along the Q. San Juan itself averaged 1.4 mg/L; across all sample sites in this study the average was 1.72 mg/L. Since nitrates are often related to human and livestock waste, higher levels of nitrates reported in this study may reflect a higher population density of both. Although Mayorga reports several small clusters of homes throughout his study area, the population density throughout the El Corpus study area is almost certainly higher.

The presence of coliform bacteria, an indicator of fecal contamination from humans and warm-blooded animals, was also detected in all water samples from the Q. San Juan. At sample site **Je**, farthest upstream, total coliform counts were only 2 per 100 ml for each of the three individual samples; all other samples from other sampling sites farther downstream were reported as ‘uncountable’ (greater than 200 per 100 ml). This would indicate that the upstream waters were less subject to the influence of biological wastes from humans or livestock. Site **Je** was located upstream of a concentrated cattle operation; cattle were penned for feeding and milking purposes on a small piece of land adjacent to a feeder stream of the Q. San Juan most times of the year. Since cattle can produce 5,400 x 10^6 coliform bacteria per head per day (Geldreich 1966 as cited in Kunkle *et al* 1987), this feedlot would be seen as a logical source of the downstream contaminants.

Urban influence: El Corpus drainage

The urban area of El Corpus is located on a flat ridge which divides the town area into two micro-watersheds, one of which is that of the Q. El Sabroso, and the other is a second, smaller drainage to the west. This stream, sampled at site **Jb,** serves as the drainage for the majority of the town of El Corpus, which explains many of the high indices of water quality degradation observed. Much of the population of the central urban area, which numbers between 1000 and 1500 persons, lives on either side of the drainage. In the center of town, and directly along the drainage, lies the entrance to the original gold mine established by the Spanish colonists in the late 1500s. Standing water is seen at the mine entrance and extends inside, even during the dry season, suggesting that groundwater regularly interacts with exposed mine residues. The stream channel itself was frequently lined with trash. Household gray water, from bathing and washing dishes and clothes, is generally drained into the landscape with no treatment. An *aguas negras* (sewage) system, which serves a portion of the town, also has its terminus in this watershed. The dominant non-urban land use along the stream banks below town (and immediately upstream of the sample point) is cattle pasture, which is burned annually (Figure 12, Chapter 3), and uphill from town the landscape is mostly smallholder annual plots and fruit trees. Water flow in the El Corpus drainage may therefore reflect some impacts from reduced forest cover. The flow of this stream diminished rapidly during the dry season; surface flow, if visible, was minimal from late March through early May. This drainage however illustrates the effects of an urban area on water quality as well. The key differences between water quality in the El Corpus drainage and the adjacent Q. San Juan are highlighted in Figure 34.

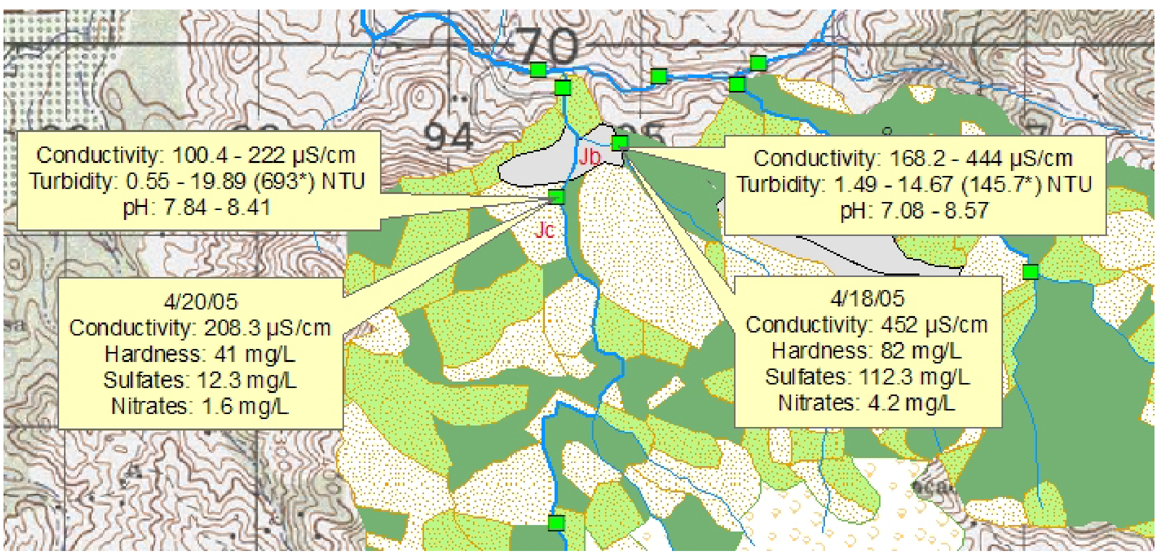

Figure 34. Water quality measurements for sample sites *Jb* and *Jc*. Conductivity, turbidity and pH field data value range during entire study period, with laboratory analysis values for dates indicated. (*) indicates value observed during high flow event on 5/20/05.

Water draining the El Corpus area was sampled at site **Jb**. While pH values at this site were similar to other sites in the study area, the conductivity values recorded were relatively high in comparison to the greater study area. Using field instruments, measured conductivity ranged from 168 to 444 µS/cm, readings which averaged higher than those in the adjacent Q. San Juan. Three water samples from site **Jb** were taken to the laboratory for analysis on 4/18/05, a time when water flow in the stream was minimal. Sulfate and nitrate measurements were relatively high as well, when compared with other sites. Whereas reported values for the Q. San Juan sample sites ranged from 0 to 24 mg/L, sulfate values reported for the three samples in the El Corpus drainage were 37, 150, and 150 mg/L. Nitrates were similarly high; where Q. San Juan values ranged from 1.0 to 1.8 mg/L, values reported for site **Jb** were much higher at 3.9, 4.2, and 4.4 mg/L.

High concentrations of nitrates can be related to agricultural fertilizers or the presence of human or animal wastes and in populated areas is often due to sewage system outflow in a surface water body (APHA 1995). For this reason elevated levels of nitrates in this drainage are not surprising, since the town wastewater system effluent discharges in this watershed and other homes, whose black water is not collected by the sewage system, may rely on old, seeping outhouses. Agricultural land use in this micro-watershed includes some cattle pasture, and relatively little land which might be chemically fertilized. Higher nitrate levels in this stream are therefore most likely the result of household and sewage system effluents, but may reflect livestock contributions as well.

Sulfate levels as well may be influenced by a variety of sources; sewage systems, municipal garbage and livestock are all possible sulfate contamination sources (US EPA 2005), and all are present upstream of the sample point. In addition to municipal wastes, water draining from the old mine under the center of town is a possible source of sulfates as a result of acid mine drainage (AMD) (Gray 1995). Mine drainage may also be linked to the high electrical conductivity values described above for this stream (AMD will be discussed in further detail below). That the El Corpus drainage is heavily impacted due to anthropogenic influences upstream of the sample point is clear; due to the variety of factors potentially degrading water quality in this stream, however, isolating the impact of historical mining from other sources of pollution in the El Corpus drainage is not easily done. On the Q. El Sabroso, however, it is much more readily apparent.

Gold mining: Quebrada El Sabroso

El Corpus has a long history of gold mining. Not only was the town founded on the presence of gold deposits, gold mining in one form or another has been a continual presence since. Whether in the form of individuals panning for gold in the streams themselves, small crushed rock mercury-amalgam operations, or the cyanide-leach pit mine in operation today, gold extraction in the area has a history as long as the town itself.

Mining operations, regardless of the product extracted or the type of operation, have been shown to have a readily visible impact on water quality. The most common effect of mining operations on water quality result from acid mine drainage (AMD). Acid mine drainage refers to the weathering of pyrite exposed as a result of mining. Following several chemical reactions, the weathering of pyrite produces iron sulfide, sulfate and hydrogen ions (acidity) (Durkin and Herrmann 1994). The acidity resulting from these processes is responsible for substantially altering the chemistry of water, as heavy metals are more readily soluble in acidic solution. In AMD, metals such as iron, cadmium, manganese, zinc and aluminum are dissolved into solution, leading to potentially harmful contamination of surface and ground water. In surface water quality studies in mining districts, sulfate and conductivity have been shown to be useful indicators of acid mine drainage. The sensitivity of conductivity to sulfate ions especially makes conductivity a useful predictor of sulfate concentrations in both AMD itself and contaminated surface waters (Gray 1995).

The water quality of the Quebrada El Sabroso presents the clearest example of the effects of mining, with consistently high levels of conductivity, sulfates and overall water hardness. A comparison between the farthest downstream points on the Q. El Sabroso, the Q. San Juan, and the upper R. Calderas is shown in Figure 35.

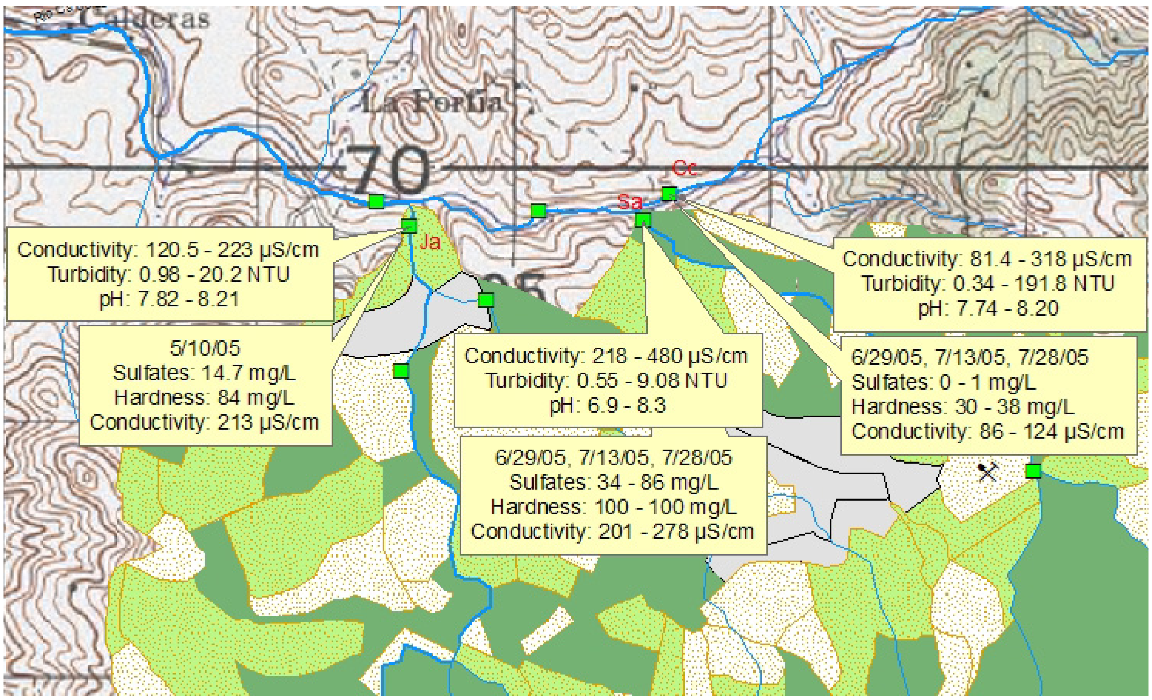

Figure 35. Water quality measurements for sample sites *Ja*, *Sa* and *Cc*. Conductivity, turbidity and pH field data value range during entire study period, with laboratory analysis values for dates indicated.

Conductivity

Data taken along the Quebrada El Sabroso reflect the mining history in the drainage and clearly points to acid mine drainage as the dominant influence in water quality degradation. Sample sites along the Q. El Sabroso consistently had the highest conductivity values in the entire study area. The confluence of the Río Calderas with El Sabroso was the site of three sample sites, **Cc** and **Cb** (on the Río Calderas above and below the confluence) and **Sa**, the most downstream sample site on the Q. El Sabroso itself. Conductivity measurements taken at site **Sa** were consistently higher, by 50-100%, than those taken simultaneously at sites **Cc** and **Cb** (Figure 36).

When examining conductivity values for Q. El Sabroso at site **Sa**, it should be noted that measurements were also consistently higher on Q. El Sabroso than at site **Ja**. Site **Ja** was the site farthest downstream on the Q. San Juan described above as having the highest conductivity values along the length of *that* stream. Despite the potential point-source runoff contributions of two urban areas (El Corpus and San Juan Abajo) immediately adjacent to the San Juan and its tributaries, the Q. El Sabroso conductivity values were clearly higher during the entire study period.

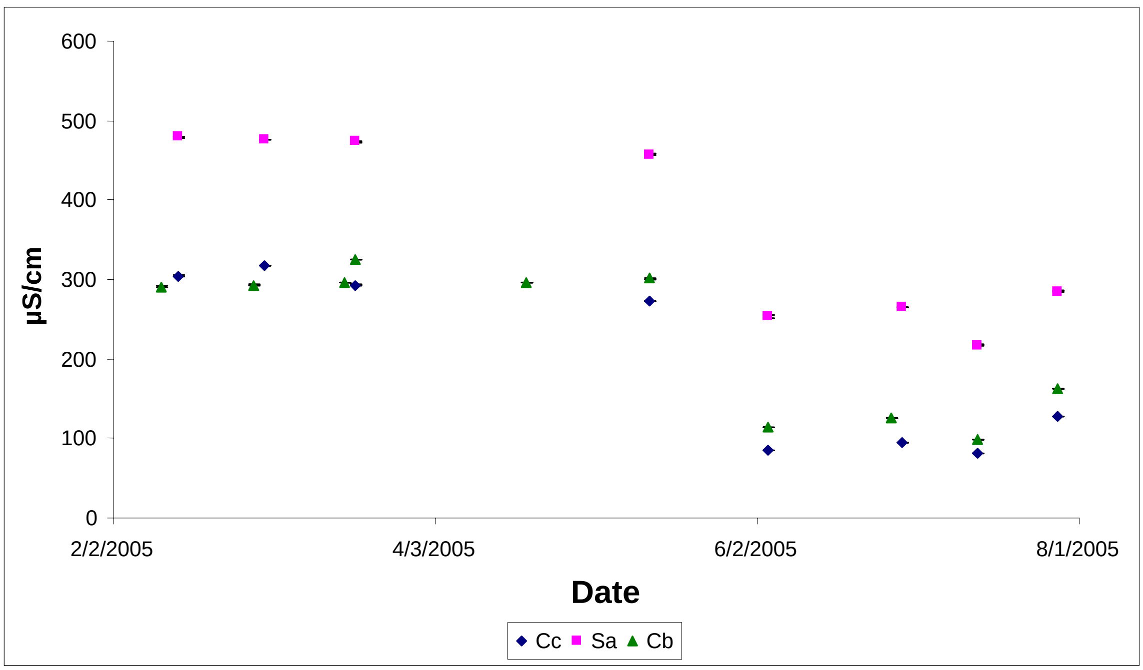

Figure 36. Conductivity values for three sample sites. Site *Sa* is located on the Q. Sabroso; *Cc* and *Cb* are located on the Río Calderas upstream and downstream of the Q. Sabroso confluence, respectively.

Laboratory analyses were performed on water samples collected simultaneously at sites **Sa**, **Cc** and **Cb** on three separate sampling days (one grab sample per site on three separate days as opposed to sampling one each on three separate days) in order to permit more direct comparisons between these particular sample points. This sampling strategy more clearly illustrated the degraded quality of water draining the El Sabroso watershed.

The most notable trend was the presence of elevated levels of sulfates at site **Sa**, on Q. El Sabroso than at sites **Cc** and **Cb** on the R. Calderas. On the three sampling occasions, the sulfate values recorded for the Q. El Sabroso site (site **Sa**) were 69, 34 and 86 mg/L. This stands in contrast to the value for the Río Calderas immediately downstream of the Sabroso confluence (site **Cb**), where sulfate values were 17, 9, and 17 mg/L on the three sampling occasions. Sulfate values upstream of the confluence at site **Cc** (and prior to the sulfate contribution of El Sabroso) were reported as 0, 1, and 65 mg/L. [It is suspected that the reading of 65 mg/L is in error due to its inconsistency with the other values reported for the sample sites **Cc** and **Cb**. Also, flow measurements taken showed that the flow rate of the upper Calderas at site **Cc** was 4.5 times that of the Sabroso on the date in question; if indeed the measurement of 65 mg/L had been correct, with the contribution of the Q. El Sabroso at 86mg/L the sulfate measurement of the lower Calderas at site **Cb** would have been substantially higher than the reported 17 mg/L.] Therefore, higher sulfate levels below the confluence can be attributed directly to the contribution of the Q. El Sabroso.

Hardness reflects the concentrations of calcium, manganese, iron and magnesium cations in the water; in the context of AMD, they would be expected to be present in elevated concentrations. At the confluence of the Q. El Sabroso and R. Calderas, water hardness values reported by the laboratory were indeed much higher at site **Sa** on the Sabroso (100 and 100 mg/L) than the upper R. Calderas at site **Cc** (30, 38 mg/L). It was therefore hypothesized that either past or present gold mining activity in the El Sabroso watershed affected the quality of water it produced.

Mine runoff

Although a handful of individual mine openings are present in the drainage, there is one active operation which clearly dwarfs all others. This active mine property directly borders the Q. El Sabroso and a small perennial water flow drains from the mine property into the stream. This water appeared rust-colored and turbid in comparison to the water of El Sabroso itself (Figure 37). The visual impact of the runoff at the point of mixing was apparent during the dry season as well, when water which appeared clear upstream became cloudy once the runoff water became mixed in. Algae were often seen at the confluence site extending for some distance downstream, but usually by 200 m downstream at sample site (**Sb**) algae was not seen in the same abundance, if at all.

Figure 37. Runoff from the gold mine property drains into the Q. El Sabroso between sample sites *Sc* and *Sb*.

The mine runoff was directly tested using field instruments on seven occasions between 11/21/04 and 7/11/05. The range of values recorded for pH ranged from 2.84 to 3.36, for conductivity from 589 to 1470 μS/cm, and for turbidity from 0.49 to 225 NTU. No flow data were obtained for the runoff, since it was located entirely on private property prior to its confluence with El Sabroso. Visual estimates would place its contribution to the flow of El Sabroso at less than 15%. To examine the influence of the active gold mine property on stream water quality, two sample sites were chosen to establish a before-and-after comparison. Site **Sc** was located approximately 200 m upstream of the gold mine property, and site **Sb** 200 m downstream. A summary of key water quality data collected at these two sites can be found in Figure 38.

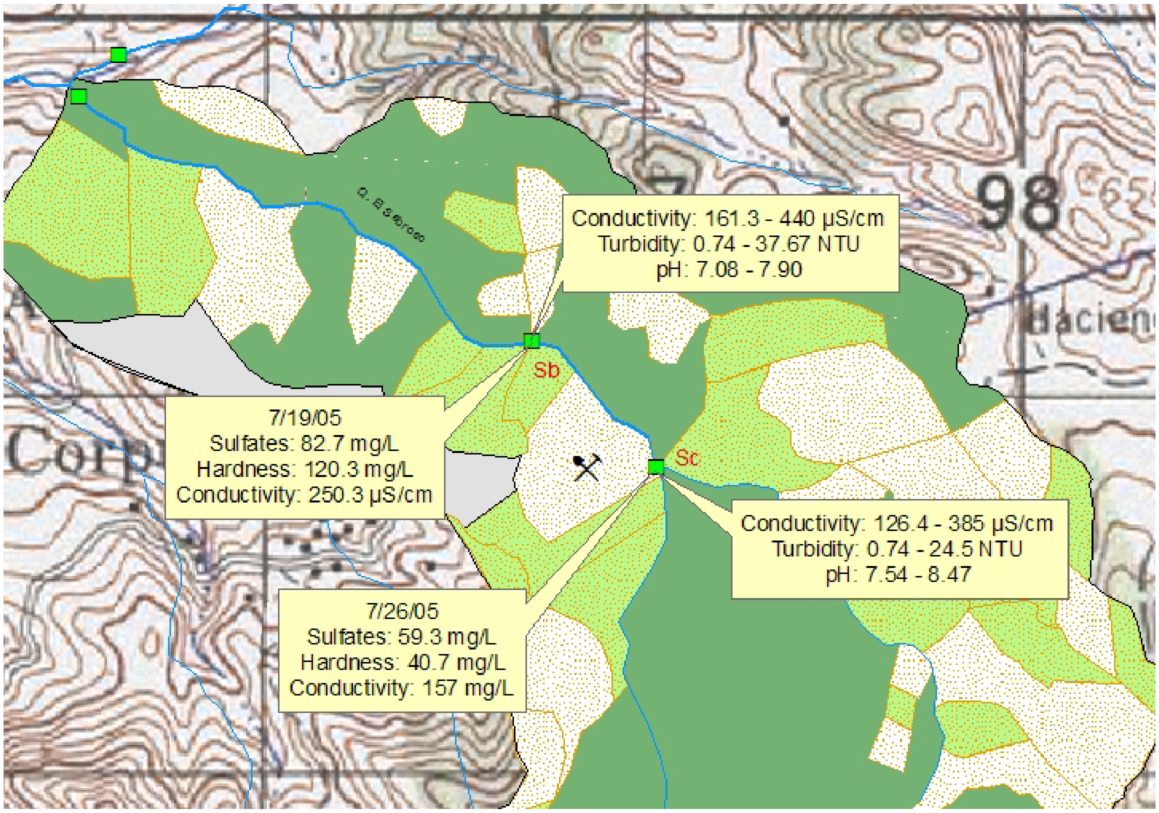

Figure 38. Water quality measurements for sample sites *Sb* and *Sc*. Conductivity, turbidity and pH field data value range during entire study period, with laboratory analysis values for dates indicated.

The runoff had a discernable effect on the conductivity of the stream water. During all sample events, the conductivity of the stream water below the mine property drainage was higher than above; differences in conductivity values between the two sites (when measured on the same day) ranged from 34.9 to 104.6 μS/cm (Figure 39).

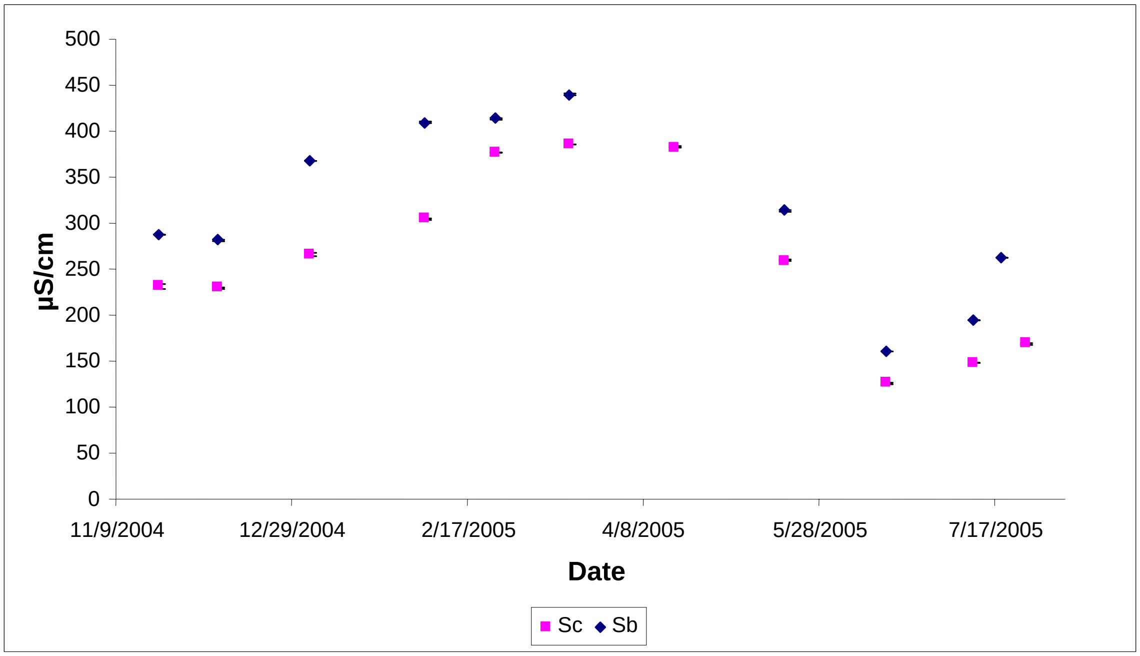

Figure 39. Conductivity values for two Q. El Sabroso sample sites. Site *Sc* is located 200 meters upstream of the mine property, *Sb* is located 200 meters downstream of the property.

pH values recorded at the two sites showed a similar trend; downstream values at site **Sb** were lower than the values upstream at site **Sc** (Figure 40). For same-day (directly comparable) sampling events, differences in pH values obtained at the two sites ranged from 0.30 to 1.61.

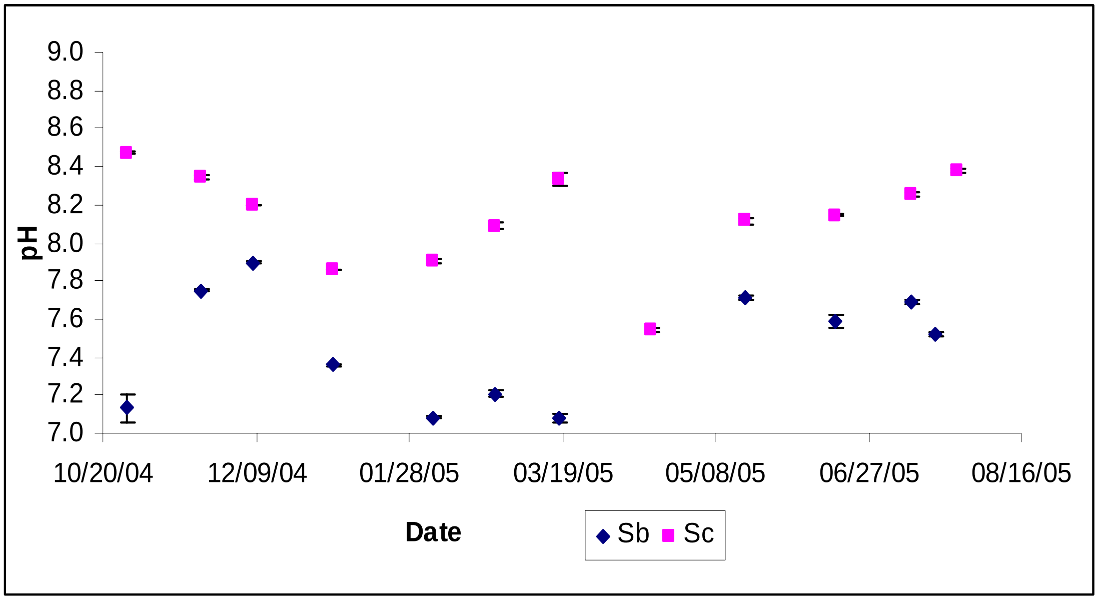

Figure 40. pH measurements at two sites on Q. El Sabroso. ***Sc*** **is upstream of the gold mine,** ***Sb*** **is downstream.**

The influence of the mine runoff on stream turbidity was more apparent during wetter periods than dry. Later in the dry season, as surface flows became minimal and eventually dried up (mid-March to early May), the contribution of mine runoff had a reduced effect on the stream water turbidity (Figure 41) at the sample site. This partly results from the lack of surface-flow connecting the mine runoff with the downstream sample site; moving through the soil under the stream bed would have filtered algae and suspended sediment from the water. As the rains began in mid-May, the difference between upstream and downstream values once again became more pronounced, with the greatest difference in turbidity coinciding with the period of highest rainfall between mid-June and mid-July.

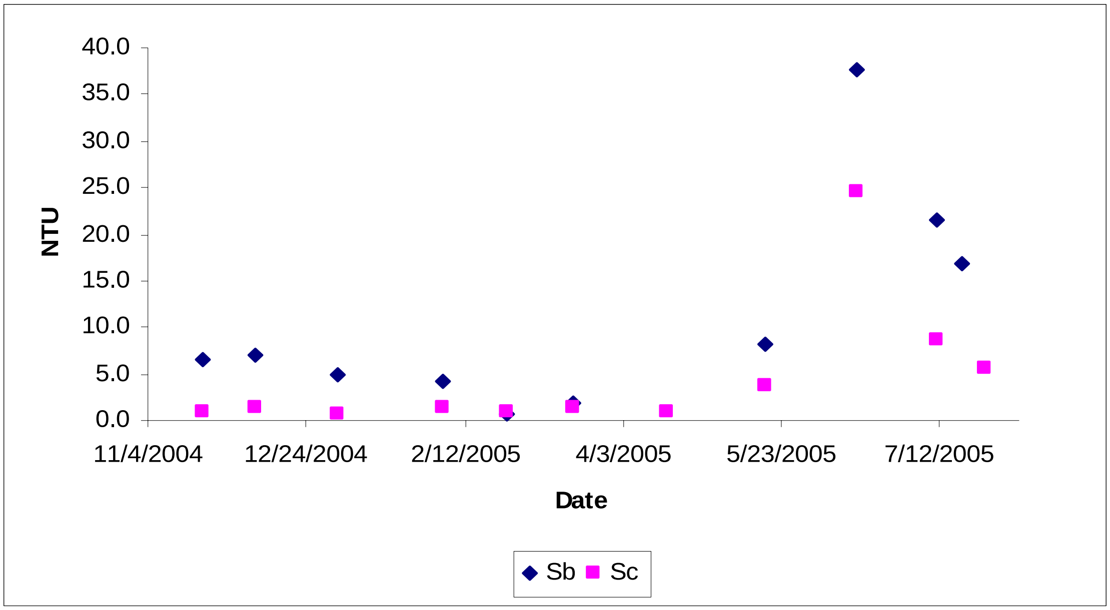

Figure 41. Turbidity values for two sample sites on the Q. El Sabroso.

In addition to field instrument observations, laboratory analysis also reflects the influence of the mine runoff. Samples were collected for laboratory analysis upstream and downstream at sites **Sc** and **Sb** as they were at all other sites in this study. However, it may be useful to relate the story of sample collection on a particular morning to further place the mine runoff in context.

Samples were collected for laboratory analysis at site **Sb** (downstream of the mine) on 7/19/05. On that particular morning, sampling was performed earlier than usual, about 6:15 am. The usual procedure followed when sampling was to measure flow rate first, followed by taking measurements with the field instruments; collection of samples for transportation to the laboratory (if applicable) was usually saved for last. On this occasion, after flow data were collected I witnessed a rapid change in the stream water. Whereas the water had been relatively clear earlier, a pulse of brown, mud-colored water came downstream. The discoloration of the water lasted approximately two to three minutes and then began to clear up. After several minutes, I performed the pH and conductivity measurements. pH was measured at 7.52 and conductivity was found to be 262 μS/cm, both well within the usual range for this site. The first of the three grab samples was then collected for laboratory analysis. At this point, a second brown-colored pulse of water appeared, similar in coloration and duration to the first. The remaining two sample bottles for laboratory analysis were then filled with this discolored water, and an additional cuvette of water was collected for turbidity analysis.

Between the time of the first grab sample, taken between pulses of discolored water, and the remaining two samples, several differences were noted. Turbidity measured between pulses with the field instrument was 16.8 NTU (laboratory value 17 NTU), while the discolored water measured 35.2 NTU (laboratory values 25 and 29 NTU). Sulfates were reported by the laboratory to be 53 mg/L in the first sample, while the remaining two samples reported values of 97 and 98 mg/L. These represent the highest sulfate readings reported across all sample sites with the exception of the El Corpus urban drainage.

Based on my knowledge of the watershed, the location of sample site **Sb** (directly downstream of the mine), the time of day (6 a.m. is shift-change at the mine), and the variable involved (sulfate), mine runoff as being the source of the brown pulses of water is the only logical conclusion.

As described above, laboratory analyses performed on water samples taken from the Q. Sabroso revealed elevated levels of hardness and sulfates. Hardness was much higher downstream of the mine drainage at site **Sb** (120, 119, 122 mg/L) than upstream at **Sc** (40, 42, 40 mg/L).Whereas in the Q. San Juan sulfate levels never exceeded 24 mg/L across all sites and sample events (and even that value may well be erroneous), in the Q. El Sabroso the lowest sulfate value reported at sites (**Sa**, **Sb**, and **Sc**) was 34 mg/L and the majority of values were in excess of 60 mg/L. Sulfate levels were higher downstream of the mine runoff than upstream. Three individual samples collected on 7/25/2005 at site **Sc** (farthest upstream) reported sulfate values of 60, 58, and 60 mg/L. Farthest downstream on the Q. El Sabroso, sulfate values (taken on three separate dates) at site **Sa** averaged higher, with values of 69, 34, and 86 mg/L. Comparing these sulfate numbers to those reported for the Cerro Guanacaure watershed, where no mining activity of any type was reported, the values in the El Sabroso clearly dwarf the average value of 4.58 mg/L reported by Mayorga (1989) in that watershed.

The location of the sample sites and the variables involved (sulfate and hardness), as well as pH and conductivity values, suggest that the contaminant source is in fact mining activity. Upstream of the larger active mining operation, high conductivity values relative to the Q. San Juan or R. Calderas may be the result of historical mining activities farther upstream in the basin. The clear and consistent increase in conductivity, acidity, and sulfates below the property suggests current mining operations are having a locally significant impact on water quality in the Quebrada El Sabroso.

DEFOMIN reports

The Honduran government agency involved in mine oversight, the Dirección Ejecutiva de Fomento a la Minería, DEFOMIN, is charged with conducting regular mine inspections and water quality examinations. DEFOMIN reports confirmed the presence of various metals in mine waters as well as the Q. El Sabroso. Two inspection reports, dated February and September 2004, can be found in Appendix 3. These examinations confirmed the presence of various metals, including manganese, zinc, nickel and copper, in both waters on the mine property and in the Q. El Sabroso. Reported contaminant levels in El Sabroso did not exceed national drinking water standards for all variables, but most were above recommended values and one, aluminum, exceeded national standards.

Chapter 7. Conclusions and Recommendations

Today the natural environment of Honduras is being challenged as never before. Meeting the needs of a rapidly expanding population has required environmental and social sacrifices. Honduras has a long history of allowing foreign companies to dominate its best agricultural land. Today the pressures and opportunities of the world economy continue to challenge the nation and its remaining natural resources. Economic alternatives, such as mining, cattle, shrimp and melon farming, to traditional agriculture are changing southern Honduras and its already heavily degraded ecology continues to suffer.

The impacts of land use on water quality are many and some are more obvious than others. As this study shows, the same problems that intensive agriculture, urban areas and extractive industries such as mining have brought to other regions of the world are visible in El Corpus. Even in one small, rural watershed one can plainly see the effects of land use on water, the most basic requirement for life. Water flows downhill; the consequences of upstream land use are felt by those who by chance or choice find themselves downstream.

Potential Health Consequences

In this case the downstream recipients of that water were my friends, neighbors and fellow residents of southern Honduras. Watching mothers and children haul water to the house, or bathe or wash clothes in the stream caused me to think about their health as well as their environment. The water draining from the Río Calderas watershed presents several potential health hazards. The most obvious, immediate and well-known to the citizenry is the risk of illness associated with bacteria and viruses in drinking water. In Honduras, national government programs, NGOs, and schools do a good job of educating people of the benefits of boiling or treating water prior to drinking, building and maintaining latrines to contain human waste, restricting the ability of livestock to contaminate water sources, and basic personal sanitation measures to prevent the spread of bacteria-vectored illness. While the level of compliance with these measures varies for a variety of reasons, most people are at least aware of this problem and have been educated on how to effectively deal with it.

Coliform and fecal coliform bacteria are commonly used indicators of biological contamination in surface waters due to human and animal waste. Although these bacteria themselves are usually harmless, their presence is considered indicative of the existence of other, more harmful, gastrointestinal bacteria and viruses. These additional contaminants are responsible for a variety of illnesses. Children especially are susceptible to these illnesses, and diarrhea continues to be a major cause of child mortality in Honduras. Of 35 countries in the Americas and the Caribbean, Honduras has the seventh highest child mortality rate (WHO 2005).

High levels of nitrate have also been linked to illness in humans. Infant methemoglobinemia ("blue-baby" syndrome) is a disease associated with exposure to high levels of nitrates, and can be fatal if untreated. The acceptable level of nitrate in drinking water has been set at less than 10mg/L in the United States (US EPA 2003). The Honduran government standards are less stringent, at 25 mg/L recommended and 50 mg/L maximum. Elevated levels of nitrate in the Q. El Sabroso and the El Corpus drainage are therefore of some concern in the context of using this water to meet domestic consumption needs. Although the nitrate values reported in this study did not exceed the US or Honduran national standards, it is important to note the values reported in this study represent individual points in time. With the presence of a concentrated population center and sewage system outlet in the watershed, the potential exists for potentially higher values to occur.

Honduran national standards set the recommended level for sulfates in drinking water at 25 mg/L, with a maximum of 250 mg/L. Sulfates are not currently enforcement-regulated by the US EPA. Possible health effects of high sulfate levels include gastro-intestinal reactions resulting in increased diarrhea (US EPA 1998).

A less well-known potential health problem is the persistence of chemical threats. This has documented in the region before. Past cotton farming has contaminated Choluteca valley groundwater with high levels of DDT and other pesticides, still found years after their use ended (Murray 1991). The presence of mining activities in watersheds creates the possibility of similar persistent problems from potentially toxic elements and compounds finding their way into the area's surface and groundwater. Citizens of El Corpus often voiced their concern over potential cyanide leaks from gold processing as a potential threat to the water in El Sabroso and the Río Calderas. This study did not address this possibility and can therefore make no statement as to its validity. Allowing cyanide to contaminate river water would be contrary to the interests of any mining company for reasons both economic and social.

Based upon the high levels of sulfates and conductivity, this study did find evidence of acid mine drainage (AMD) in the Sabroso watershed. AMD is also a strong possibility in the waters draining the town of El Corpus as well, again due to the high levels of sulfates and conductivity found. Heavy metals such as arsenic, lead, cadmium and mercury are toxic to humans and cause a variety of long term health effects, and have been associated with AMD. In developed nations, where water sources and systems are usually tested and treated prior to human consumption, the human health effects of acid mine drainage are often avoided. In developing nations, such as Honduras, this is not necessarily the case. Further, the effects of AMD do not disappear once a mine ceases operation. Mines may continue to contribute acid drainage for hundreds or even thousands of years (Peplow 1999). Mining operations last until a resource is exhausted, then are closed and abandoned. The short-term economic benefits of mine are real and tangible, but so are the long-term environmental damages they cause. Environmental remediation is complex and expensive (Durkin and Herrmann 1994).

The problem of erosion

The problems of soil erosion are also long term in nature and difficult to address. This study has shown that stream water quality reflects soil erosion from the agricultural lands in these watersheds. The problem of erosion and resulting water quality has negative impacts on downstream water users, and reflects serious land degradation in the mountain watersheds where it occurs.

On hillside lands, agricultural productivity declines with topsoil loss as fewer nutrients are available to crops. Inputs such as fertilizers are therefore more necessary to sustain yields, and these become necessary more frequently as they wash off with the rains, further impacting resulting water quality. Declining productivity on limited land increases economic difficulties for farming families.

Downstream problems include increased water treatment costs for consumption or agriculture. In the case of the Gulf of Fonseca, sediment from mountain watersheds poses threats to water quality in the mangrove estuaries and their inhabitants. The need to continually remove sludge from shrimp farms carries an acknowledged economic cost to both artisan (small-scale) and industrial operations (Samayoa *et al.* 2000). Downstream agricultural interests which rely on surface water for irrigation must also deal with sediment-laden waters. Compounding the problem of turbidity in water, upstream chemical contaminants are often carried downstream via sediment.

Downstream users of water, whether agricultural producers, individual families, municipal water systems or ecological communities, will also have to confront the continued problem of reduced flows, especially during dry periods. Reductions in forest cover interrupt the natural water flow regimen, and flows cannot be expected to improve without improvements in upstream forest integrity, especially in crucial watersheds. To supplement meager or non-existent water flows during certain time periods, many agricultural producers in the region use supplemental groundwater; it is possible that this resource, with reduced replenishment from mountain watersheds, will soon become scarce as well.

Recommendations

This study examined water quality indicators over a relatively short period of time. Regular testing is the most reliable way to determine current conditions and identify long-term trends. This should be made a priority by the local and national government. Occasional or infrequent testing is not sufficient to ensure that water is safe for human use. Inspections should be more frequent and more comprehensive than currently practiced. When considering potential industrial contamination, visits by health and environmental compliance personnel should be unannounced, frequent, and thorough. Water samples should analyzed for the broadest possible spectrum of potentially threatening substances.

Further, certain additional steps may be called for in this situation. Specifically, potable water systems should be considered for the families that live or obtain their water directly downstream of current mining operations. While the urban center of El Corpus has the benefit of obtaining its tap water from relatively clean sources at higher elevations, many families even close to town do not have connections to this system. Farther downstream additional homes are located along the river and are potentially at risk. In the event that these families obtain their drinking or household water from the streams, new extensions or smaller additional systems should be built to serve these families with clean water.

Well water does not necessarily represent an advantage over surface water. The majority of water wells in the area are open, hand-dug wells from which water is extracted using a rope-and-bucket system. These wells present their own contamination problems, especially with respect to potential biological contamination from wild and domestic animal feces. Ideally, these wells would be sealed; many assistance projects in the area do in fact upgrade these wells with caps and install human-powered pumps to reduce potential contamination. This is not yet universal however.

To the extent that these wells currently do provide an alternative to river water, during the rainy season the direct effluent from mining operations may be avoided through their use. The continual interchange between surface and groundwater, however, suggests that these water sources may be contaminated to some extent. Regular testing of these wells should be instituted, with tested parameters above and beyond the standard coliform bacteria analysis performed by public health personnel.

The problem of erosion is multi-faceted. It has been recognized by experts from many fields as a problem affecting the environmental and economic health of developing nations. Like many environmental problems, there are no quick solutions where thousands of individual landowners and competing interests are involved. Many projects and programs have addressed soil and water conservation and erosion reduction. The potential avenues to action are numerous, however, as this study has shown, it is a problem that continues to require attention.

This six-month study, like the periodic testing described above, offers only a moment's glance at water quality in the Río Calderas. The mining operations in the watershed are continually expanding; it is quite probable that historical mining has impacted water quality in the area for some time before the current owners assumed responsibility for the mine in its present form. Indeed, the high levels of sulfates in the El Corpus drainage may be evidence that mining which concluded many years ago still contaminates the water to this day. Mine operations in the area are expanding, however. From renovations and expansions begun in 2004, operations continue to increase production. It would not be expected that water quality impacts could be reduced while simultaneously increasing output. Also, the acquisition of additional mining rights in the

Baldoquin area to the south of current operations threatens to further impact water resources, and possibly expand impacts into an additional watershed.

This report does not aim to weigh the social benefits of expanded agriculture, increased employment, and municipal and national revenues against environmental damage. However, studies and periodic inspections by competent agencies allow citizens to make more informed choices. Educational limitations in Honduras may prevent ordinary citizens from understanding the detailed cause and effect of environmental damage, but the level of concern for *el ambiente* in Honduras today attests to their desire to see their land and water used in a responsible manner which benefits all citizens.

Communities and societies need reliable water sources in order to function and grow. This is as true in the developing world as it is in the developed. The stability of countries around the world is predicated on their ability to meet citizens' needs; their success or failure in this arena forms an inherent risk to their stability. Citizens demand personal security and economic opportunity. Around the world, failure to maintain certain levels of environmental integrity is a cause of hunger, disease, and associated social chaos. Hopefully, the Honduran government and its citizens will find the right balance between environmental protection and economic opportunity that is crucial to the nation's long-term success.

Literature Cited

Almendares, J., Sierra, M., Anderson, P.K. and P. Epstein, 1993. Critical regions, a profile of Honduras. *The Lancet* **342**: 1400-1402.

APHA-AWWA-AWRA. 1995. *Standard Methods for the Examination of Water and Wastewater*, 19th ed. American Public Health Association, Washington, DC.

Boyer, J. 1982. *Agrarian Capitalism and Peasant Praxis in Southern Honduras*. Unpublished Ph.D. dissertation, University of North Carolina at Chapel Hill.

Brower, A.M. 2000. Honduras: an ethnographic study of El Armado National Wildlife Refuge and Guayape, Olancho. Unpublished master's thesis, Michigan Technological University.

Bruijnzeel, L.A. 1988. (De)forestation and dry season flow in the tropics: A closer look. *Journal of Tropical Forest Science* **1** (3): 229-243.

Campbell, G.C. and Wildberger, S. 1992. *The Monitor's Handbook.* Chestertown, MD: LaMotte Company.

Canter, L.W. 1985. *River water quality monitoring*. Chelsea, Michigan: Lewis Publishers.

Central Intelligence Agency (CIA). 2005. CIA World Factbook, 2005.

Center for Economic and Social Rights (CESR). 2001. The Price of Gold: Gold Mining & Human Rights Violations in Honduras. Available online at: http://www.cesr.org/honduras.

Centro Internacional de Agricultura Tropical (CIAT). 2001. Atlas de Honduras. Available at: http://gisweb.ciat.cgiar.org/cross_scale/atlas-mitch.htm.

COHDEFOR 1994. *Estudio preliminar de la cuenca Guanacaure*. CARE-DIMACH-COHDEFOR, September 1994. 79 pages.

DeWalt, B.R. 1985. Microcosmic and macrocosmic processes of agrarian change in Southern Honduras: The cattle are eating the forest. In *Micro and Macro Levels of Analysis in Anthropology: Issues in Theory and Research*, B.R. DeWalt and P.J. Pelto, eds., pp.165-186. Boulder, Colo.: Westview.

-------. 2000. Testimony to the Subcommittee on Western Hemisphere, the Peace Corps, Narcotics and Terrorism of the Senate Committee on Foreign Relations – July 25, 2000. Available at: http://www.pitt.edu/~brdewalt/testimony.html. Accessed September 19, 2005.

DeWalt, B.R. and Stonich, S.C. 1999. Inequality, population, and forest destruction in Honduras. In *Population and Deforestation in the Humid Tropics,* Richard E. Bilsborrow and Daniel Hogan, eds., pp. 152-174. International Union for the Scientific Study of Population, Campinas, Brazil

Dunne, T. 1979. Sediment yield and land use in tropical catchments. *Journal of Hydrology* **42**: 281-300.

Dunne, T. and Leopold, L. B. 1978. *Water in environmental planning*. New York: W.H. Freemand and Company.

Durkin, T.V. and Herrmann, J.G. 1994. Focusing on the problem of mining wastes: An introduction to acid mine drainage. Reprint From EPA Seminar Publication no. EPA/625/R-95/007 "Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites".

EarthTrends. 2003. Biodiversity and Protected Areas – Honduras. EarthTrends Country Profiles, World Resources Institute. Available online at: http://earthtrends.wri.org/; accessed September 30, 2005.

Elvir, A.R. 1974. Mapa Geológico de la República de Honduras (Geologic Map of the Republic of Honduras). Tegucigalpa, Honduras: Instituto Geográfico Nacional.

El-Swaify, S.A. and Dangler, E.W. 1982. Rainfall erosion in the tropics: A state-of-the-art. In *Soil Erosion and Conservation in the Tropics*, Kussow, W. (ed.) 1982. ASA Special Publication Number 43. American Society of Agronomy. Madison WI.

EPYPSA Consultores. 2002. *Diagnostico Biofísico socioeconómico de la zona sur*: *Fichas – Diagnostico de los Municipios de Mambocaure*. Dinámica y Situación Actual de la Mancomunidad MAMBOCAURE: Proyecto de Planificación Territorial. PRODEMHON-AMHON.

FAO. 2005. *State of the world's forests*. Rome: Food and Agriculture Organization of the United Nations.

Gareau, B.J. 2004. Use and exchange value in development projects in southern Honduras. *Capitalism Nature Socialism* **15** (3): 95-110.

Geldreich, E.E. 1966. Sanitary significance of fecal coliforms in the environment. (Water Pollution Control Research Series, Publ. WP-20-3.) FWPCA, USDI, Cincinnati, OH.

Gray, N.F. 1995. Field assessment of acid mine drainage contamination in surface and ground water. *Environmental Geology* **27**: 358-361.

Government of Honduras. 1995. *Norma técnica nacional para la calidad del agua potable*. Tegucigalpa: Republica de Honduras Ministerio de Salud: Comité técnico nacional de calidad del agua CTN-CALAGUA-CAPRE.

-------. 2000. Interim Poverty Reduction Strategy Paper. Tegucigalpa, Honduras. Available online at: http://www.imf.org/external/NP/prsp/2000/hnd/01/.

Harcourt, C., and Sayer. J., ed. 1996. *Conservation atlas of tropical forests: the Americas*. New York: Simon & Schuster.

Hargreaves, G. 1992. Hydrometerological data for Honduran water resources development. Utah Sate University, Dept. of Biological and Irrgation Engineering. Logan, UT.

Hellin, J. and Larrea, S. 1997. The use of vegetation for better land husbandry: Project ZF0019/R6292CB Final Technical Report 01.07.95 – 30.09.97. Forestry Research Programme, Department for International Development (UK). Available at: www.frp.uk.com/dissemination_documents/R6292_-_FTR.pdf; accessed September 21, 2005.

Kunkle S. and Comer, G. H. 1972. Suspended, bed, and dissolved sediment loads in the Sleepers River, Vermont. Agricultural Research Service, USDA.

Kunkle, S. and J. Wilson. 1984. *Specific conductance and pH measurements in surface waters: An introduction for park natural resource specialists*. WRFSL Report no. 84-4. Fort Collins, CO: Water Resources Field Support Laboratory.

Kunkle, S., Johnson, W.S., and Flora, M. 1997. *Monitoring stream water for land-use impacts: A training manual for natural resource management specialists*. Water Resources Division, National Park Service.

Leonard, H. J. 1987. *Natural Resources and Economic Development in Central America*. International Institute for Environment and Development. Washington, D.C.: Transaction Books.

Mayorga, J.J. 1989. Water quality of low stream flows on the Cerro Guanacaure Watershed, Choluteca, Honduras. Unpublished Master's thesis, University of Arizona.

Mikhailova, E.A., Bryant, R.B., Schwager, S.J. and Smith, S.D. 1997. Predicting rainfall erosivity in Honduras. *Soil Science Society of America Journal* **61**: 273-279.

Montoya, M.Z. 2005. Personal communication. Biologist in charge of water laboratory at *Aguas de Choluteca,* Choluteca, Honduras.

Murphy, P. G. and A. E. Lugo. 1986. Ecology of tropical dry forest. *Annual Review of Ecology and Systematics* **17**: 66-88.

Murray, D.L. 1991. Export agriculture, ecological disruption, and social inequity: Some effect of pesticides in southern Honduras. *Agriculture and Human Values*. Fall 1991: 19-29.

Norsworthy, K, and T. Barry, 1994. *Inside Honduras*. Resource Center Press. Albuquerque, NM. 208 pp.

Peplow, D. 1999. *Environmental impacts of mining in eastern Washington*. Center for Water and Watershed Studies fact sheet, University of Washington. Available at: http://depts.washington.edu/cwws/Outreach/FactSheets/mine.pdf.

Population Reference Bureau, 2005. 2005 World Population Data Sheet. Available online: http://www.prb.org/pdf05/05WorldDataSheet_Eng.pdf.

PROGOLFO. 1999. *Diagnóstico del Estado de los Recursos Naturales, Socioeconómicos e Institucionales de la Zona Costera del Golfo de Fonseca*. Proyecto Regional, Conservación de los Ecosistemas Costeros del Golfo de Fonseca (PROGOLFO), DANIDA/UICN/ORMA/Secretaría de Recursos Naturales y Ambiente de Honduras, Ministerio de Medio Ambiente y Recursos Naturales de El Salvador, Ministerio del Ambiente y Recursos Naturales de Nicaragua, Costa Rica, 1999.

Richards, M. 1996. Protected areas, people and incentives in the search for sustainable forest conservation in Honduras. *Environmental Conservation* **23** (3): 207-217.

Rivera, S. 2004. Testing best management practices for protecting water quality in Honduras. Unpublished PhD. Dissertation, Utah State University.

Samayoa A.M., Thurow A.P. and Thurow T.L. 2000. A watershed-level economic assessment of the downstream effects of steepland erosion on shrimp production, Honduras. Technical Bulletin No. 00-1, USAID-Soil Management CRSP/Texas A&M University, College Station, Texas.

Sanchez, P.A. 1976. *Properties and management of soils in the tropics*. New York: Wiley and Sons.

Santos, H., Thurow A.P. and T.L. Thurow. 2000. Linkages between investment in extension services and farmers’ adoption of soil conservation practicies in southern Honduras. USAID – Soil Management Collaborative Research Support Program Texas A&M University Technical Bulletin No. 2000-02.

Stone, Doris. 1973. The Archaeology of Central and Southern Honduras. Peabody Museum of Archaeology and Ethnology. Harvard University 49 (3): 1-135.

Stonich, S. and Dewalt, B.R. 1996. The Political Ecology of Deforestation in Honduras. In *Tropical Deforestation: The Human Dimension,* L. Sponsel, T. Headland and R. Bailey, eds., pp. 187-215. New York: Columbia University Press.

Thompson, M. 1992. The effect of stone retention walls on soil productivity and crop performance on selected hillside farms in southern Honduras. Tropsoils, Texas A&M University.

Thurow T.L. and Smith J.E. 1998. Assessment of soil and water conservation methods applied to cultivated steeplands of southern Honduras. Technical Bulletin No. 98-2. USAID-Soil Management CRSP/Texas A&M University, College Station, Texas.

Thurow A.P, Thurow T. and H. Santos. 2004. Considerations for targeting soil conservation investments in southern Honduras. *Environment and Development Economics* **9**: 781-802.

Toness, A.S., Thurow, T.L. and Hector E. Sierrra. 1998. Sustainable management of tropical steeplands: An assessment of terraces as a soil and water conservation technology. USAID – Soil Management Collaborative Research Support Program Texas A&M University Technical Bulletin No. 98-1

US Agency for International Development (USAID). 1990. Agricultural sector strategy paper. Tegucigalpa, Honduras: Office of Agriculture and Rural Development, USAID.

US Department of State, 2005. Background Note: Honduras. http://www.state.gov/r/pa/ei/bgn/1922.htm; accessed September 25, 2005.

US Environmental Protection Agency (EPA). 1998. Health effects from exposure to sulfate in drinking water workshop. Office of Water, US Environmental Protection Agency. Available at http://www.epa.gov/safewater/standard/wrksum.pdf.

-------. 2003. Water on tap: what you need to know. Office of Water, US Environmental Protection Agency. Available at http://www.epa.gov/safewater/.

-------. 2005. Potential sources of drinking water contamination index. Office of Water, US Environmental Protection Agency Available at: http://www.epa.gov/safewater/swp/sources1.html

US Library of Congress, 1993. Country Studies: Honduras. Country Studies/Area Handbook Series, Library of Congress Federal Research Division. Available at: http://countrystudies.us/honduras/

Velasco, Pablo. 2000. The mineral industries of Central America – Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. US Geological Survey Minerals Yearbook 2000, pp. 6.1-6.12.

Ward, A.D. and Trimble, S.W. 2004. *Environmental hydrology*. 2nd ed. New York: Lewis Publishers.

WHO 2005. Countries – Honduras (selected indicators). World Health Organization. Available at: http://www.who.int/countries/hnd/en/ Accessed Nov. 12, 2005.

Wischmeier, W.H. and Smith, D.D. 1978. *Predicting rainfall erosion losses – a guide to conservation planning*. USDA Handbook No. 537.

World Climate. 2005. Climate Data for 13°N 87°W. http://www.worldclimate.com/cgi-bin/grid.pl?gr=N13W087; accessed 9/13/05.

Zamorano (Escuela Agrícola Panamericano). 2004. Suelos de la cuenca baja del Río Choluteca. Proyecto Manejo de la Cuenca del Ríos Choluteca y Negro. Unidad de Suelos, Zamorano. Unpublished CD-ROM.

Appendix 1. Field data

Field measurements grouped by stream name; sites listed starting farthest upstream. All values reported to instrument precision.

- Condensed summary tables for each site
- Individual measurements

Legend:

Variable	***Explanation / Units***	***Method***
temppH	Water temperature, ^{o}C	(Extech ExStik pH100)
pH	pH	(ExTech Exstik pH100)
tempcond	Water temperature, ^{o}C	(Extech ExStik EC400)
cond	Conductivity, μS/cm	(Extech ExStik EC400)
ppm	Total dissolved solids, mg/L	(Extech ExStik EC400)
turb	Turbidity, NTU	(Oakton T100)
flow	m^3/sec	Cross sectional method 0 = no or unmeasurable (minimal) flow

Quebrada El Sabroso
Site: **Sc**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
10/28/2004	25.3	8.47					
11/21/2004	23.4	8.34	23.8	231	163.0	0.87	
12/8/2004	23.4	8.20	23.8	230	158.3	1.31	
1/3/2005	22.6	7.86	23.0	266	189.0	0.74	
2/5/2005	22.6	7.90	22.9	305	213	1.45	
2/25/2005	23.7	8.09	24.2	377	263	0.99	0.0000
3/18/2005	25.2	8.33	25.6	385	269	1.40	0.0000
4/17/2005	25.7	7.54	26.2	382	266	0.91	0.0000
5/18/2005	25.5	8.11	25.9	260	181.8	3.82	0.0079
6/16/2005	24.8	8.14	25.3	126.4	87.3	24.5	0.5905
7/11/2005	23.9	8.25	24.4	148.8	104.2	8.75	0.3451
7/26/2005	23.4	8.38	23.8	168.8	119.1	5.58	0.5093

All measurements (Site **Sc**)

date	temppH	pH	tempcond	cond	ppm	turb	flow
10/28/04	78.2	8.47					
10/28/04	77.6	8.48					
10/28/04	77.4	8.48					
10/28/04	77.3	8.45					
10/28/04	77.2	8.48					
11/21/04	23.5	8.35	23.8	227	163	0.90	
11/21/04	23.4	8.32	23.8	232	163	1.12	
11/21/04	23.4	8.36	23.8	235	163	0.99	
11/21/04						0.85	
11/21/04						0.81	
11/21/04						0.87	
11/21/04						0.86	
11/21/04						0.80	
11/21/04						0.81	
11/21/04						0.71	
12/08/04	23.4	8.20	23.8	231	159	1.41	
12/08/04	23.4	8.20	23.8	230	158	1.50	
12/08/04	23.3	8.19	23.8	228	158	1.33	
12/08/04						1.32	
12/08/04						1.01	
01/03/05	22.7	7.87	23.1	263	189	0.81	
01/03/05	22.6	7.87	23.0	266	189	0.83	
01/03/05	22.6	7.86	23.0	270	189	0.59	
01/03/05						0.71	
01/03/05						0.58	
01/03/05						0.85	
01/03/05						0.87	
01/03/05						0.64	
01/03/05						0.88	
01/03/05						0.59	
02/05/05	22.6	7.94	22.9	304	212	1.74	
02/05/05	22.6	7.91	22.9	304	214	1.29	
02/05/05	22.6	7.87	22.9	306	214	1.44	
02/05/05	22.6	7.89	22.9	305	212	1.55	
02/05/05	22.6	7.89	22.9	304	211	1.33	
02/05/05						1.32	
02/05/05						2.11	
02/05/05						1.21	
02/05/05						1.09	
02/05/05						1.39	

Site **Sc**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/25/05	23.7	8.07	24.2	376	262	1.01	0.0000
02/25/05	23.7	8.14	24.2	377	263	1.15	
02/25/05	23.7	8.10	24.2	376	262	1.14	
02/25/05	23.7	8.06	24.2	377	263	0.92	
02/25/05	23.7	8.08	24.2	377	263	1.24	
02/25/05						0.81	
02/25/05						1.04	
02/25/05						0.86	
02/25/05						0.84	
02/25/05						0.89	
03/18/05	25.2	8.32	25.6	387	269	1.22	0.0000
03/18/05	25.2	8.46	25.6	385	268	1.28	
03/18/05	25.2	8.29	25.6	384	263	1.51	
03/18/05	25.2	8.28	25.6	385	273	1.53	
03/18/05	25.2	8.30	25.6	386	270	1.30	
03/18/05						1.31	
03/18/05						1.25	
03/18/05						1.61	
03/18/05						1.51	
03/18/05						1.47	
04/17/05	25.7	7.56	26.2	380	266	0.94	0.0000
04/17/05	25.7	7.54	26.2	383	267	0.78	
04/17/05	25.7	7.50	26.2	382	267	1.14	
04/17/05	25.7	7.54	26.2	383	265	0.95	
04/17/05	25.7	7.55	26.2	384	266	0.87	
04/17/05						0.95	
04/17/05						0.98	
04/17/05						0.94	
04/17/05						0.70	
04/17/05						0.84	
05/18/05	25.5	8.16	25.9	260	182	3.78	0.0079
05/18/05	25.5	8.07	25.9	257	182	3.73	
05/18/05	25.5	8.11	25.9	261	183	3.80	
05/18/05	25.5	8.10	25.9	260	181	3.70	
05/18/05	25.5	8.13	25.9	260	181	4.06	
05/18/05						3.68	
05/18/05						3.82	
05/18/05						3.80	
05/18/05						3.71	
05/18/05						4.14	

Site **Sc**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
06/16/05	24.8	8.14	25.3	125.7	87.2	25.20	0.5905
06/16/05	24.8	8.15	25.3	125.8	87.3	24.10	
06/16/05	24.8	8.14	25.3	125.7	87.5	24.50	
06/16/05	24.8	8.13	25.3	128.8	87.3	24.10	
06/16/05	24.8	8.16	25.3	125.8	87.0	23.90	
06/16/05						24.40	
06/16/05						25.20	
06/16/05						25.10	
06/16/05						24.00	
06/16/05						24.10	
07/11/05	23.9	8.26	24.4	149.5	104.4	8.38	0.3451
07/11/05	23.9	8.24	24.4	148.7	104.4	9.14	
07/11/05	23.9	8.23	24.4	149.4	103.8	9.14	
07/11/05	23.9	8.23	24.4	148.3	104.3	8.68	
07/11/05	23.9	8.29	24.4	148.2	104.2	8.40	
07/11/05						8.82	
07/11/05						9.20	
07/11/05						8.93	
07/11/05						8.52	
07/11/05						8.31	
07/26/05	23.4	8.39	23.8	167.4	119.2	5.58	0.5093
07/26/05	23.4	8.36	23.8	168.1	118.3	5.05	
07/26/05	23.4	8.38	23.8	169.2	120.4	4.94	
07/26/05	23.4	8.42	23.8	168.8	118.4	6.06	
07/26/05	23.4	8.35	23.8	170.6	119.2	6.31	
07/26/05						5.70	
07/26/05						6.00	
07/26/05						5.53	
07/26/05						5.46	
07/26/05						5.19	

Quebrada El Sabroso

Site: **Mine runoff**

Summary

date	temppH	pH	tempcond	cond	ppm	turb
10/28/2004	25.8	3.06				
11/21/2004	24.4	3.13	24.8	1005	701	27.07
12/8/2004	24.3	3.36	24.8	589	413	52.50
1/3/2005	22.5	3.16	23.2	1170	819	0.49
2/25/2005	23.4	3.34	22.7	1424	1003	1.94
6/16/2005	25.9	2.91	26.5	1470	1039	86.60
7/11/2005	24.4	2.84	26.0	1407	1000	225.40

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
10/28/04	25.7	3.08					
10/28/04	25.7	3.05					
10/28/04	25.8	3.05					
10/28/04	25.8	3.05					
10/28/04	25.9	3.05					
11/21/04	25.0	3.15	24.9	1004	702	27.60	
11/21/04	24.3	3.12	24.8	1005	701	26.70	
11/21/04	24.4	3.12	24.8	1005	701	27.50	
11/21/04						26.00	
11/21/04						27.10	
11/21/04						27.10	
11/21/04						27.00	
11/21/04						27.20	
11/21/04						27.30	
11/21/04						27.20	
12/08/04	24.3	3.37	25.0	587	412	53.00	
12/08/04	24.3	3.36	24.8	589	413	53.10	
12/08/04	24.3	3.36	24.8	590	414	52.50	
12/08/04						52.40	
12/08/04						51.50	

Mine runoff
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
01/03/05	22.6	3.17	23.2	1170	819	0.50	
01/03/05	22.5	3.15	23.2	1171	820	0.57	
01/03/05	22.5	3.17	23.2	1170	819	0.28	
01/03/05						0.79	
01/03/05						0.35	
01/03/05						1.07	
01/03/05						0.43	
01/03/05						0.27	
01/03/05						0.40	
01/03/05						0.28	
02/25/05	23.4	3.31	22.7	1425	1003	2.27	
02/25/05	23.4	3.35	22.7	1426	1008	2.16	
02/25/05	23.4	3.40	22.7	1420	998	2.64	
02/25/05	23.4	3.36	22.7	1423	1002	2.06	
02/25/05	23.4	3.30	22.7	1425	1002	2.20	
02/25/05						1.56	
02/25/05						1.63	
02/25/05						1.25	
02/25/05						1.66	
06/16/05	25.9	2.92	26.5	1469	1027	86.00	
06/16/05	25.9	2.91	26.5	1473	1048	86.90	
06/16/05	25.9	2.92	26.5	1470	1040	86.50	
06/16/05	25.9	2.90	26.5	1468	1038	87.40	
06/16/05	25.9	2.91	26.5	1470	1040	87.00	
06/16/05						87.10	
06/16/05						86.70	
06/16/05						86.50	
06/16/05						86.00	
06/16/05						85.90	
07/11/05	24.4	2.81	26.0	1406	1004	224.00	
07/11/05	24.4	2.90	26.0	1412	1003	225.00	
07/11/05	24.4	2.78	26.0	1404	1000	227.00	
07/11/05	24.4	2.95	26.0	1402	998	228.00	
07/11/05	24.4	2.78	26.0	1409	996	226.00	
07/11/05						225.00	
07/11/05						226.00	
07/11/05						224.00	
07/11/05						224.00	
07/11/05						225.00	

Quebrada El Sabroso

Site **Sb**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
10/28/2004	25.4	7.13					
11/21/2004	23.3	7.75	23.9	288	201	6.48	
12/8/2004	24.2	7.90	24.7	281	193	7.12	0.0163
1/3/2005	22.3	7.36	23.0	368	257	4.83	
2/5/2005	24.0	7.08	24.5	409	288	4.22	
2/25/2005	23.3	7.21	23.6	414	286	0.74	0.0000
3/18/2005	25.6	7.08	26.0	440	294	1.92	0.0000
5/18/2005	25.6	7.71	26.0	313	220	8.28	0.0051
6/16/2005	24.7	7.59	25.2	161.3	113.1	37.67	0.5905
7/11/2005	24.1	7.69	24.5	193.8	135.4	21.45	0.3451
7/19/2005	23.5	7.52	23.9	262	183.4	16.80	0.5093

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
10/28/04	26.0	6.85					
10/28/04	25.3	7.12					
10/28/04	25.3	7.22					
10/28/04	25.2	7.22					
10/28/04	25.1	7.24					
11/21/04	23.3	7.74	24.4	288	201	6.77	
11/21/04	23.2	7.75	24.1	286	202	7.12	
11/21/04	23.3	7.74	23.9	288	201	6.62	
11/21/04	23.2	7.75	23.9	288	201	6.25	
11/21/04	23.3	7.76	23.9	289	201	6.13	
11/21/04						6.40	
11/21/04						6.53	
11/21/04						6.39	
11/21/04						6.26	
11/21/04						6.28	
12/08/04	24.3	7.90	24.7	282	185.0	6.92	0.0163
12/08/04	24.2	7.90	24.7	281	196.0	7.20	
12/08/04	24.2	7.89	24.7	281	197.0	7.18	
12/08/04						7.23	
12/08/04						7.07	

Site **Sb**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
01/03/05	22.3	7.37	23.1	368	256	5.92	
01/03/05	22.3	7.36	23.0	368	256	4.89	
01/03/05	22.3	7.35	23.0	367	258	4.73	
01/03/05						4.79	
01/03/05						4.58	
01/03/05						4.62	
01/03/05						4.82	
01/03/05						4.62	
01/03/05						4.56	
01/03/05						4.77	
02/05/05	24.1	7.07	24.5	409	291	4.92	
02/05/05	24.1	7.10	24.5	410	289	4.16	
02/05/05	24.0	7.09	24.5	406	287	3.58	
02/05/05	24.0	7.06	24.5	410	288	3.67	
02/05/05	24.0	7.10	24.5	411	287	3.41	
02/05/05						4.79	
02/05/05						4.20	
02/05/05						4.39	
02/05/05						4.72	
02/05/05						4.32	
02/25/05	23.3	7.15	23.6	413	285	1.06	0.0000
02/25/05	23.3	7.20	23.6	413	287	0.58	
02/25/05	23.3	7.21	23.6	414	287	0.56	
02/25/05	23.3	7.23	23.6	415	287	0.99	
02/25/05	23.3	7.25	23.6	413	286	0.60	
02/25/05						0.96	
02/25/05						0.53	
02/25/05						0.77	
02/25/05						0.70	
02/25/05						0.61	
03/18/05	25.6	7.16	26.0	439	296	1.74	0.0000
03/18/05	25.6	7.05	26.0	441	294	2.66	
03/18/05	25.6	7.08	26.0	438	294	1.92	
03/18/05	25.6	7.02	26.0	440	293	2.21	
03/18/05	25.6	7.10	26.0	441	293	1.75	
03/18/05						3.63	
03/18/05						1.04	
03/18/05						1.06	
03/18/05						2.14	
03/18/05						1.09	

Site **Sb**
Continued

date	temppH	pH	tempcond	Cond	ppm	turb	flow
05/18/05	25.6	7.71	26.0	313	220	8.18	0.0051
05/18/05	25.6	7.73	26.0	315	219	8.08	
05/18/05	25.6	7.67	26.0	312	220	8.24	
05/18/05	25.6	7.72	26.0	312	219	8.34	
05/18/05	25.6	7.72	26.0	315	221	8.27	
05/18/05						7.98	
05/18/05						8.25	
05/18/05						8.29	
05/18/05						8.28	
05/18/05						8.86	
06/16/05	24.7	7.67	25.2	161.3	113.1	37.70	0.5905
06/16/05	24.7	7.66	25.2	161.5	113.2	37.30	
06/16/05	24.7	7.51	25.2	160.9	112.6	37.90	
06/16/05	24.7	7.60	25.2	160.9	114.0	37.00	
06/16/05	24.7	7.49	25.2	161.7	112.6	37.90	
06/16/05						37.70	
06/16/05						37.60	
06/16/05						38.20	
06/16/05						38.00	
06/16/05						37.40	
07/11/05	24.1	7.66	24.5	194.1	135.5	21.50	0.3451
07/11/05	24.1	7.71	24.5	193.7	135.3	21.40	
07/11/05	24.1	7.68	24.5	193.8	135.3	21.00	
07/11/05	24.1	7.69	24.5	193.9	135.4	22.20	
07/11/05	24.1	7.70	24.5	193.7	135.5	21.70	
07/11/05						21.60	
07/11/05						21.70	
07/11/05						21.20	
07/11/05						21.10	
07/11/05						21.10	
07/19/05	23.5	7.55	23.9	264	184	17.02	0.5093
07/19/05	23.5	7.50	23.9	262	184	16.63	
07/19/05	23.5	7.51	23.9	261	182	17.01	
07/19/05	23.5	7.49	23.9	261	184	16.28	
07/19/05	23.5	7.55	23.9	263	183	16.86	
07/19/05						16.70	
07/19/05						16.68	
07/19/05						17.76	
07/19/05						16.48	
07/19/05						16.55	

Quebrada El Sabroso

Site **Sa**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
2/14/2005	23.0	7.7	23.5	480	335	1.77	0.0003
3/2/2005	26.1	8.0	26.6	476	335	0.62	0.0006
3/19/2005	27.2	7.3	27.6	473	329	1.50	0.0000
5/13/2005	27.4	6.9	27.9	458	320	0.55	0.0000
6/4/2005	26.3	8.0	26.6	254	173	9.08	0.0738
6/29/2005	24.2	8.2	24.6	265	186	8.72	0.1614
7/13/2005	24.8	8.2	25.3	218	151	8.09	0.6031
7/28/2005	24.6	8.3	25.0	285	197	7.51	0.1311

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/14/05	23.0	7.70	23.5	477	335	0.97	0.0003
02/14/05	23.0	7.69	23.5	481	334	1.34	0.0003
02/14/05	23.0	7.71	23.5	480	333	0.88	0.0003
02/14/05	23.0	7.71	23.5	479	335	3.43	0.0003
02/14/05	23.0	7.70	23.5	482	336	2.52	0.0003
02/14/05						2.05	0.0003
02/14/05						1.75	0.0003
02/14/05						1.53	0.0003
02/14/05						2.06	0.0003
02/14/05						1.21	0.0003
03/02/05	26.1	7.97	26.6	478	333	0.28	0.0006
03/02/05	26.1	7.98	26.6	476	335	0.32	0.0006
03/02/05	26.1	7.98	26.6	476	336	0.84	0.0006
03/02/05	26.1	7.95	26.6	475	334	0.62	0.0006
03/02/05	26.1	8.00	26.6	477	336	0.80	0.0006
03/02/05						0.53	0.0006
03/02/05						0.54	0.0006
03/02/05						0.54	0.0006
03/02/05						1.04	0.0006
03/02/05						0.67	0.0006

Site **Sa**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
03/19/05	27.2	7.31	27.6	473	328	0.79	0.0000
03/19/05	27.2	7.30	27.6	471	329	3.22	0.0000
03/19/05	27.2	7.33	27.6	474	328	0.24	0.0000
03/19/05	27.2	7.32	27.6	475	329	1.65	0.0000
03/19/05	27.2	7.33	27.6	474	330	0.50	0.0000
03/19/05						0.53	0.0000
03/19/05						3.36	0.0000
03/19/05						3.06	0.0000
03/19/05						1.22	0.0000
03/19/05						0.40	0.0000
05/13/05	27.4	6.89	27.9	456	319	0.45	0.0000
05/13/05	27.4	6.88	27.9	455	320	0.45	0.0000
05/13/05	27.4	6.90	27.9	460	321	0.57	0.0000
05/13/05	27.4	6.87	27.9	457	319	0.53	0.0000
05/13/05	27.4	6.87	27.9	460	322	0.78	0.0000
05/13/05						0.60	0.0000
05/13/05						0.51	0.0000
05/13/05						0.52	0.0000
05/13/05						0.54	0.0000
05/13/05						0.55	0.0000
06/04/05	26.3	7.98	26.6	254	175	10.15	0.0738
06/04/05	26.3	7.99	26.6	258	176	8.88	0.0738
06/04/05	26.3	7.98	26.6	257	170	9.22	0.0738
06/04/05	26.3	8.02	26.6	249	174	8.54	0.0738
06/04/05	26.3	8.01	26.6	251	172	8.64	0.0738
06/04/05						10.16	0.0738
06/04/05						8.89	0.0738
06/04/05						8.45	0.0738
06/04/05						8.45	0.0738
06/04/05						9.40	0.0738
06/29/05	24.2	8.19	24.6	264	185	8.82	0.1614
06/29/05	24.2	8.15	24.6	266	186	8.66	0.1614
06/29/05	24.2	8.17	24.6	265	186	8.46	0.1614
06/29/05	24.2	8.20	24.6	264	187	8.39	0.1614
06/29/05	24.2	8.16	24.6	265	185	8.62	0.1614
06/29/05						9.02	0.1614
06/29/05						8.75	0.1614
06/29/05						8.79	0.1614
06/29/05						8.80	0.1614
06/29/05						8.85	0.1614

Site **Sa**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
07/13/05	24.8	8.21	25.3	218	151	8.06	0.6031
07/13/05	24.8	8.22	25.3	218	151	8.23	0.6031
07/13/05	24.8	8.19	25.3	217	149	7.55	0.6031
07/13/05	24.8	8.18	25.3	218	151	8.51	0.6031
07/13/05	24.8	8.19	25.3	217	151	7.93	0.6031
07/13/05						8.33	0.6031
07/13/05						8.09	0.6031
07/13/05						7.55	0.6031
07/13/05						9.05	0.6031
07/13/05						7.64	0.6031
07/28/05	24.6	8.35	25.0	287	196	6.35	0.1311
07/28/05	24.6	8.39	25.0	284	195	8.33	0.1311
07/28/05	24.6	8.33	25.0	283	198	7.38	0.1311
07/28/05	24.6	8.37	25.0	286	197	7.10	0.1311
07/28/05	24.6	8.35	25.0	286	197	7.09	0.1311
07/28/05						7.71	0.1311
07/28/05						7.90	0.1311
07/28/05						7.92	0.1311
07/28/05						7.84	0.1311
07/28/05						7.48	0.1311

Río Calderas
Site **Cc**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
2/14/2005	22.3	7.86	22.9	305	213	2.12	
3/2/2005	26.7	7.74	27.2	318	223	0.34	0.0035
3/19/2005	27.5	7.80	28.0	293	203	0.53	0.0040
5/13/2005	28.3	7.84	28.8	274	191.8	1.87	0.0034
6/4/2005	25.7	7.96	26.1	84.4	60.3	13.90	0.3345
6/29/2005	24.3	7.89	24.9	94.6	65.6	11.22	1.3651
7/13/2005	24.7	8.02	25.1	81.4	56.7	7.86	1.7256
7/28/2005	25.3	8.20	25.6	127.6	89.3	3.79	1.0482

All measurements (Site **Cc**)

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/14/05	22.4	7.88	22.9	300	212	2.58	
02/14/05	22.3	7.90	22.9	304	214	3.51	
02/14/05	22.4	7.83	22.9	307	213	1.86	
02/14/05	22.3	7.83	22.9	305	212	1.94	
02/14/05	22.3	7.86	22.9	308	212	2.83	
02/14/05						1.13	
02/14/05						1.67	
02/14/05						1.98	
02/14/05						1.32	
02/14/05						2.42	
03/02/05	26.7	7.62	27.2	318	223	0.35	0.0035
03/02/05	26.7	7.67	27.2	319	224	0.29	
03/02/05	26.7	7.79	27.2	318	223	0.32	
03/02/05	26.7	7.80	27.2	316	223	0.26	
03/02/05	26.7	7.83	27.2	317	222	0.30	
03/02/05						0.33	
03/02/05						0.51	
03/02/05						0.44	
03/02/05						0.25	
03/02/05						0.34	
03/19/05	27.5	7.81	28.0	295	204	0.94	0.0040
03/19/05	27.5	7.80	28.0	292	205	0.70	
03/19/05	27.5	7.82	28.0	294	202	0.53	
03/19/05	27.5	7.78	28.0	293	201	0.47	
03/19/05	27.5	7.81	28.0	292	203	0.23	
03/19/05						0.22	
03/19/05						0.64	
03/19/05						0.36	
03/19/05						0.49	
03/19/05						0.75	
05/13/05	28.3	7.85	28.8	274	193	2.90	0.0034
05/13/05	28.3	7.84	28.8	273	193	1.55	
05/13/05	28.3	7.82	28.8	274	191	1.54	
05/13/05	28.3	7.86	28.8	273	192	2.78	
05/13/05	28.3	7.85	28.8	274	190	1.01	
05/13/05						3.26	
05/13/05						1.46	
05/13/05						1.54	
05/13/05						1.61	
05/13/05						1.08	

Site **Cc**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
06/04/05	25.7	7.94	26.1	84.3	61.6	14.05	0.3345
06/04/05	25.7	7.96	26.1	84.2	61.3	15.00	
06/04/05	25.7	7.95	26.1	85.5	58.9	13.46	
06/04/05	25.7	7.99	26.1	84.4	60.9	14.46	
06/04/05	25.7	7.97	26.1	84.4	59.0	14.34	
06/04/05						13.46	
06/04/05						14.08	
06/04/05						13.20	
06/04/05						13.77	
06/04/05						13.15	
06/29/05	24.3	7.91	24.9	94.7	66.0	13.54	1.3651
06/29/05	24.3	7.92	24.9	93,9	65.7	10.51	
06/29/05	24.3	7.84	24.9	94.8	65.5	9.90	
06/29/05	24.3	7.90	24.9	94.6	65.6	14.54	
06/29/05	24.3	7.88	24.9	95.1	65.0	10.03	
06/29/05						12.39	
06/29/05						9.67	
06/29/05						9.34	
06/29/05						10.79	
06/29/05						11.47	
07/13/05	24.7	8.03	25.1	81.4	57.0	8.07	1.7256
07/13/05	24.7	8.01	25.1	81.2	56.9	7.85	
07/13/05	24.7	8.03	25.1	81.5	56.9	8.04	
07/13/05	24.7	8.00	25.1	81.5	56.4	7.62	
07/13/05	24.7	8.01	25.1	81.3	56.4	7.46	
07/13/05						7.80	
07/13/05						7.98	
07/13/05						8.31	
07/13/05						7.76	
07/13/05						7.71	
07/28/05	25.3	8.20	25.6	127.5	89.3	4.05	1.0482
07/28/05	25.3	8.19	25.6	127.8	89.1	3.84	
07/28/05	25.3	8.23	25.6	128.3	89.6	3.89	
07/28/05	25.3	8.16	25.6	127.2	88.9	3.97	
07/28/05	25.3	8.22	25.6	127.4	89.9	4.13	
07/28/05						3.07	
07/28/05						3.38	
07/28/05						4.10	
07/28/05						3.90	
07/28/05						3.52	

Río Calderas

Site **Cb**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
2/11/2005	23.5	7.42	24.1	291	206	2.19	0.0035
2/28/2005	26.9	7.69	27.4	293	205	0.57	0.0014
3/17/2005	27.5	7.62	27.9	296	207	0.68	0.0036
3/19/2005	27.5	7.22	28.0	325	227	0.61	0.0000
4/20/2005	27.6	7.61	28.1	296	209	0.44	0.0000
5/13/2005	28.5	7.87	29.0	301	212	0.64	0.0017
6/4/2005	25.9	7.98	26.3	114.5	79.9	32.30	0.3515
6/29/2005	24.6	8.07	25.0	126.6	88.7	7.42	
7/13/2005	25.0	8.03	25.4	99.0	69.6	8.21	1.2678
7/28/2005	24.8	8.29	25.2	162.2	113.9	4.97	0.3848

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/11/05	23.5	7.29	24.1	293	206	1.54	0.0035
02/11/05	23.5	7.26	24.1	295	205	2.18	
02/11/05	23.5	7.49	24.1	289	207	2.23	
02/11/05	23.5	7.53	24.1	286	205	2.89	
02/11/05	23.5	7.55	24.1	293	207	2.32	
02/11/05						1.28	
02/11/05						2.72	
02/11/05						1.83	
02/11/05						2.48	
02/11/05						2.42	
02/28/05	26.9	7.69	27.4	293	205	0.62	0.0014
02/28/05	26.9	7.71	27.4	294	204	0.39	
02/28/05	26.9	7.68	27.4	292	205	0.48	
02/28/05	26.9	7.68	27.4	291	205	0.70	
02/28/05	26.9	7.69	27.4	294	205	0.53	
02/28/05						0.91	
02/28/05						0.51	
02/28/05						0.45	
02/28/05						0.51	
02/28/05						0.59	

Site **Cb**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
03/17/05	27.5	7.60	27.9	295	207	0.38	0.0036
03/17/05	27.5	7.63	27.9	296	208	0.37	
03/17/05	27.5	7.63	27.9	295	207	0.69	
03/17/05	27.5	7.62	27.9	298	207	0.92	
03/17/05	27.5	7.62	27.9	297	208	0.99	
03/17/05						0.50	
03/17/05						0.63	
03/17/05						1.10	
03/17/05						0.33	
03/17/05						0.93	
03/19/05	27.5	7.21	28.0	326	227	0.46	0.0000
03/19/05	27.5	7.20	28.0	324	226	1.21	
03/19/05	27.5	7.26	28.0	324	226	0.52	
03/19/05	27.5	7.23	28.0	325	227	0.39	
03/19/05	27.5	7.20	28.0	324	228	0.61	
03/19/05						0.63	
03/19/05						0.76	
03/19/05						1.07	
03/19/05						0.08	
03/19/05						0.41	
04/20/05	27.6	7.66	28.1	295	208	0.29	0.0000
04/20/05	27.6	7.63	28.1	298	207	0.28	
04/20/05	27.6	7.62	28.1	294	209	0.60	
04/20/05	27.6	7.55	28.1	296	209	0.41	
04/20/05	27.6	7.58	28.1	298	210	0.49	
04/20/05						0.43	
04/20/05						0.39	
04/20/05						0.35	
04/20/05						0.64	
04/20/05						0.50	
05/13/05	28.5	7.87	29.0	301	212	0.68	0.0017
05/13/05	28.5	7.85	29.0	300	211	0.56	
05/13/05	28.5	7.89	29.0	303	210	0.55	
05/13/05	28.5	7.90	29.0	300	214	0.56	
05/13/05	28.5	7.82	29.0	301	213	0.51	
05/13/05						0.52	
05/13/05						0.60	
05/13/05						0.86	
05/13/05						0.85	
05/13/05						0.68	

Site **Cb**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
06/04/05	25.9	7.99	26.3	115.3	80.0	35.40	0.3515
06/04/05	25.9	7.98	26.3	114.4	79.5	31.20	
06/04/05	25.9	7.97	26.3	114.8	79.9	31.40	
06/04/05	25.9	7.95	26.3	114.2	80.0	36.00	
06/04/05	25.9	8.00	26.3	113.9	79.9	30.10	
06/04/05						31.00	
06/04/05						33.60	
06/04/05						31.10	
06/04/05						30.90	
06/04/05						32.30	
06/27/05	24.6	8.10	25.0	126.6	88.6	7.34	
06/27/05	24.6	8.09	25.0	126.5	88.7	7.28	
06/27/05	24.6	8.04	25.0	126.7	88.8	7.28	
06/27/05	24.6	8.03	25.0	126.6	88.6	7.35	
06/27/05	24.6	8.07	25.0	126.4	88.7	8.02	
06/27/05						7.29	
06/27/05						7.30	
06/27/05						7.35	
06/27/05						7.50	
06/27/05						7.51	
07/13/05	25.0	8.04	25.4	98.9	69.0	8.15	1.2678
07/13/05	25.0	8.02	25.4	99.2	70.5	8.15	
07/13/05	25.0	8.05	25.4	99.8	69.6	8.15	
07/13/05	25.0	8.09	25.4	99.0	69.3	8.23	
07/13/05	25.0	7.98	25.4	98.2	69.5	8.55	
07/13/05						8.11	
07/13/05						8.43	
07/13/05						7.98	
07/13/05						7.69	
07/13/05						8.68	
07/28/05	24.8	8.25	25.2	162.0	113.6	4.64	0.3848
07/28/05	24.8	8.30	25.2	162.1	114.2	4.96	
07/28/05	24.8	8.31	25.2	161.8	114.1	4.72	
07/28/05	24.8	8.28	25.2	162.5	113.8	7.51	
07/28/05	24.8	8.30	25.2	162.4	113.8	4.36	
07/28/05						4.92	
07/28/05						5.11	
07/28/05						4.62	
07/28/05						4.51	
07/28/05						4.34	

Río Calderas

Site **Ca**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
12/10/2004	23.6	8.30	24.1	204	144.0	1.27	
1/5/2005	27.9	8.63	28.4	216	150.2	2.67	0.0694
2/11/2005	23.8	8.01	24.1	224	154.6	2.23	0.0216
2/28/2005	27.0	8.09	27.5	219	148.8	0.89	0.0212
3/17/2005	27.8	8.04	28.2	223	154.6	1.42	0.0164
3/29/2005	28.6	8.18	29.1	219	153.0	0.90	0.0177
4/20/2005	28.1	8.03	28.4	231	160.8	2.03	0.0233
5/13/2005	28.3	7.99	28.8	226	157.4	2.53	0.0304
6/4/2005	27.6	8.21	28.1	135.7	95.1	11.48	0.3837
7/8/2005	25.7	8.06	26.2	115.2	80.2	17.32	2.2727

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
12/10/04	23.6	8.30	24.1	201	145	1.47	
12/10/04			24.1	203	143	1.22	
12/10/04			24.1	207	144	1.23	
12/10/04						1.58	
12/10/04						1.38	
12/10/04						1.05	
12/10/04						1.16	
12/10/04						1.45	
12/10/04						1.03	
12/10/04						1.15	
01/05/05	28.0	8.60	28.4	217	151	2.49	0.0694
01/05/05	27.9	8.63	28.4	217	151	2.89	
01/05/05	27.9	8.65	28.5	215	147	3.04	
01/05/05	27.9	8.64	28.3	216	151	2.34	
01/05/05	27.9	8.65	28.4	217	151	2.88	
01/05/05						2.83	
01/05/05						2.59	
01/05/05						2.47	
01/05/05						2.18	
01/05/05						2.99	

Site **Ca**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/11/05	23.8	7.99	24.1	224	156	1.54	0.0216
02/11/05	23.8	8.00	24.1	224	152	2.18	
02/11/05	23.8	8.05	24.1	223	157	2.23	
02/11/05	23.8	7.97	24.1	224	153	2.89	
02/11/05	23.8	8.02	24.1	223	155	2.32	
02/11/05						1.28	
02/11/05						2.72	
02/11/05						2.48	
02/11/05						2.42	
02/28/05	27.0	8.07	27.5	219	144	0.65	0.0212
02/28/05	27.0	8.09	27.5	218	147	0.64	
02/28/05	27.0	8.11	27.5	219	151	1.23	
02/28/05	27.0	8.09	27.5	218	151	0.65	
02/28/05	27.0	8.08	27.5	219	151	1.00	
02/28/05						1.12	
02/28/05						0.97	
02/28/05						1.21	
02/28/05						0.70	
02/28/05						0.69	
03/17/05	27.8	8.03	28.2	223	155	1.91	0.0164
03/17/05	27.8	8.05	28.2	223	156	1.44	
03/17/05	27.8	8.04	28.2	223	155	2.03	
03/17/05	27.8	8.05	28.2	223	154	1.29	
03/17/05	27.8	8.04	28.2	223	154	1.27	
03/17/05						1.40	
03/17/05						1.33	
03/17/05						1.19	
03/17/05						1.12	
03/17/05						1.19	
03/29/05	28.6	8.19	29.1	219	152	0.90	0.0177
03/29/05	28.6	8.17	29.1	220	153	0.76	
03/29/05	28.6	8.18	29.1	219	153	0.71	
03/29/05	28.6	8.16	29.1	220	153	0.84	
03/29/05	28.6	8.18	29.1	219	154	0.86	
03/29/05						0.71	
03/29/05						1.17	
03/29/05						0.90	
03/29/05						1.28	
03/29/05						0.84	

Site **Ca**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
04/20/05	28.1	8.04	28.4	232	160	1.04	0.0233
04/20/05	28.1	8.03	28.4	230	161	3.02	
04/20/05	28.1	8.02	28.4	231	162	3.67	
04/20/05	28.1	8.05	28.4	230	160	2.13	
04/20/05	28.1	8.01	28.4	230	161	1.50	
04/20/05						2.24	
04/20/05						1.60	
04/20/05						1.59	
04/20/05						1.70	
04/20/05						1.77	
05/13/05	28.3	8.00	28.8	226	156	2.44	0.0304
05/13/05	28.3	8.01	28.8	226	158	2.80	
05/13/05	28.3	7.99	28.8	225	157	2.07	
05/13/05	28.3	7.98	28.8	225	158	2.29	
05/13/05	28.3	7.99	28.8	226	158	2.73	
05/13/05						2.54	
05/13/05						2.16	
05/13/05						3.21	
05/13/05						2.71	
05/13/05						2.37	
06/04/05	27.6	8.21	28.1	136.2	95.1	11.41	0.3837
06/04/05	27.6	8.20	28.1	136.6	95.3	11.37	
06/04/05	27.6	8.23	28.1	135.3	94.7	11.45	
06/04/05	27.6	8.20	28.1	135.4	95.2	11.06	
06/04/05	27.6	8.19	28.1	135.2	95.3	12.73	
06/04/05						11.32	
06/04/05						11.08	
06/04/05						10.90	
06/04/05						11.56	
06/04/05						11.92	
07/08/05	25.7	8.05	26.2	116.0	80.5	17.16	2.2727
07/08/05	25.7	8.07	26.2	114.8	80.5	17.20	
07/08/05	25.7	8.05	26.2	115.1	80.3	17.06	
07/08/05	25.7	8.04	26.2	115.0	80.2	16.63	
07/08/05	25.7	8.09	26.2	115.3	79.6	18.00	
07/08/05						17.25	
07/08/05						17.38	
07/08/05						16.77	
07/08/05						17.87	
07/08/05						17.92	

Quebrada San Juan

Site **Je**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
2/10/2005	21.4	7.87	21.6	142.8	99.9	1.43	
3/4/2005	24.0	7.48	24.5	144.6	101.0	0.99	0.0065
4/1/2005	24.1	7.60	24.6	147.3	103.5	0.94	0.0019
4/21/2005	26.7	7.25	27.4	145.9	100.5	0.78	0.0035
5/19/2005	24.0	7.42	24.4	147.6	103.6	1.26	0.0067
6/27/2005	27.0	7.71	27.2	128.0	89.2	2.93	0.0114

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/10/05	21.5	7.89	21.6	142.6	100.2	1.43	
02/10/05	21.4	7.89	21.6	143.0	99.9	1.60	
02/10/05	21.4	7.92	21.6	142.7	99.0	1.14	
02/10/05	21.4	7.82	21.6	143.7	100.3	2.47	
02/10/05	21.4	7.81	21.6	142.1	100.1	1.86	
02/10/05						1.34	
02/10/05						1.06	
02/10/05						1.15	
02/10/05						1.32	
02/10/05						0.97	
03/04/05	24.0	7.50	24.5	142.5	101.2	1.28	0.0065
03/04/05	24.0	7.49	24.5	144.6	101.6	0.85	
03/04/05	24.0	7.45	24.5	145.5	100.4	0.76	
03/04/05	24.0	7.46	24.5	145.4	100.9	0.74	
03/04/05	24.0	7.49	24.5	145.1	101.1	1.07	
03/04/05						0.86	
03/04/05						0.86	
03/04/05						0.88	
03/04/05						1.56	
03/04/05						1.05	
04/01/05	24.1	7.68	24.6	148.3	102.3	1.30	0.0185
04/01/05	24.1	7.57	24.6	147.5	103.6	1.33	
04/01/05	24.1	7.59	24.6	146.1	103.9	0.84	
04/01/05	24.1	7.56	24.6	147.8	103.6	0.99	
04/01/05	24.1	7.60	24.6	146.8	104.2	0.74	
04/01/05						0.75	
04/01/05						1.02	
04/01/05						0.91	
04/01/05						0.85	
04/01/05						0.68	

Site **Je**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
04/21/05	26.7	7.25	27.4	146.3	101.6	0.62	0.0035
04/21/05	26.7	7.24	27.4	146.2	98.7	0.61	
04/21/05	26.7	7.27	27.4	145.9	101.4	0.99	
04/21/05	26.7	7.27	27.4	146.0	102.5	0.84	
04/21/05	26.7	7.23	27.4	145.3	98.1	0.73	
04/21/05						0.85	
04/21/05						0.76	
04/21/05						0.86	
04/21/05						0.63	
04/21/05						0.86	
05/19/05	24.0	7.39	24.4	147.3	103.6	1.21	0.0067
05/19/05	24.0	7.43	24.4	147.7	103.5	1.18	
05/19/05	24.0	7.42	24.4	147.8	103.4	1.13	
05/19/05	24.0	7.47	24.4	147.9	103.7	1.14	
05/19/05	24.0	7.41	24.4	147.4	103.8	1.42	
05/19/05						1.40	
05/19/05						1.47	
05/19/05						1.13	
05/19/05						1.42	
05/19/05						1.11	
06/27/05	27.0	7.74	27.2	128.1	89.4	2.34	0.1136
06/27/05	27.0	7.64	27.2	127.9	89.6	3.29	
06/27/05	27.0	7.78	27.2	128.0	88.9	3.11	
06/27/05	27.0	7.69	27.2	128.1	89.1	2.55	
06/27/05	27.0	7.70	27.2	127.8	88.8	2.35	
06/27/05						3.38	
06/27/05						2.91	
06/27/05						3.16	
06/27/05						2.70	
06/27/05						3.54	

Quebrada San Juan
Site **Jd**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
11/1/2004	26.7	8.35					
2/10/2005	20.5	8.25	20.8	164.0	114.5	1.44	0.0107
4/1/2005	24.2	8.36	24.6	167.8	117.3	0.82	0.0247
4/21/2005	28.7	8.88	29.2	172.3	118.3	1.52	0.0232
5/19/2005	24.0	8.32	24.4	172.5	120.6	2.57	0.0150
6/10/2005	24.6	7.99	24.9	115.2	80.1	33.19	0.3568

All measurements (Site **Jd**)

date	temppH	pH	tempcond	cond	ppm	turb	flow
11/01/04	27.1	8.31					
11/01/04	26.9	8.36					
11/01/04	26.7	8.37					
11/01/04	26.5	8.36					
11/01/04	26.1	8.34					
02/10/05	20.6	8.25	20.8	163.6	115.8	1.33	0.0107
02/10/05	20.5	8.25	20.8	164.2	115.5	1.23	0.0107
02/10/05	20.5	8.34	20.8	161.6	111.7	0.92	0.0107
02/10/05	20.5	8.23	20.8	165.6	114.3	1.98	0.0107
02/10/05	20.5	8.20	20.8	164.9	115.1	1.23	0.0107
02/10/05						1.25	0.0107
02/10/05						1.44	0.0107
02/10/05						1.61	0.0107
02/10/05						2.55	0.0107
02/10/05						0.86	0.0107
04/01/05	24.2	8.39	24.6	167.2	117.8	0.81	0.0247
04/01/05	24.2	8.36	24.6	166.8	117.4	0.67	0.0247
04/01/05	24.2	8.33	24.6	169.0	117.2	0.61	0.0247
04/01/05	24.2	8.35	24.6	167.3	117.1	0.59	0.0247
04/01/05	24.2	8.36	24.6	168.9	116.8	0.81	0.0247
04/01/05						0.82	0.0247
04/01/05						0.94	0.0247
04/01/05						0.89	0.0247
04/01/05						1.17	0.0247
04/01/05						0.87	0.0247
04/21/05	28.7	8.85	29.2	172.4	115.2	1.50	0.0232
04/21/05	28.7	8.90	29.2	170.1	120.3	1.27	0.0232
04/21/05	28.7	8.89	29.2	173.3	117.8	1.96	0.0232
04/21/05	28.7	8.87	29.2	172.8	118.0	1.63	0.0232
04/21/05	28.7	8.90	29.2	173.0	120.1	1.85	0.0232
04/21/05						1.47	0.0232
04/21/05						0.92	0.0232
04/21/05						1.59	0.0232
04/21/05						1.11	0.0232
04/21/05						1.87	0.0232

Site **Jd**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
05/19/05	24.0	8.36	24.4	172.4	120.7	2.36	0.0150
05/19/05	24.0	8.34	24.4	172.6	120.6	2.37	0.0150
05/19/05	24.0	8.30	24.4	172.4	120.6	3.11	0.0150
05/19/05	24.0	8.31	24.4	172.4	120.7	2.62	0.0150
05/19/05	24.0	8.30	24.4	172.6	120.6	2.41	0.0150
05/19/05						2.45	0.0150
05/19/05						2.28	0.0150
05/19/05						2.75	0.0150
05/19/05						2.77	0.0150
05/19/05						2.53	0.0150
06/10/05	24.6	7.96	24.9	115.7	80.0	32.60	0.3568
06/10/05	24.6	7.95	24.9	115.2	80.1	32.70	0.3568
06/10/05	24.6	8.01	24.9	115.2	79.9	32.90	0.3568
06/10/05	24.6	7.97	24.9	114.9	80.2	32.30	0.3568
06/10/05	24.6	8.08	24.9	115.1	80.1	32.70	0.3568
06/10/05						32.50	0.3568
06/10/05						34.50	0.3568
06/10/05						33.60	0.3568
06/10/05						34.10	0.3568
06/10/05						34.00	0.3568

Quebrada San Juan

Site **Jc**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
1/5/2005	25.9	8.41	26.2	190.8	134.1	2.38	
2/28/2005	25.0	7.95	25.6	202	143.4	2.15	0.0197
3/17/2005	26.3	7.99	26.7	211	145.8	1.11	0.0255
4/20/2005	25.8	8.11	26.3	219	154.2	0.55	0.0350
5/10/2005	28.5	8.00	29.0	222	151.2	1.76	0.0241
5/20/2005	24.6	7.84	25.2	100.4	69.7	693	1.2670
6/2/2005	26.0	8.24	26.6	147.5	102.8	19.89	0.5464
7/8/2005	25.2	8.12	25.7	111.6	77.8	16.58	1.0137

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
01/05/05	25.8	8.42	26.3	191.3	134.1	2.17	
01/05/05	25.9	8.40	26.3	190.7	134.2	2.68	
01/05/05			26.3	190.6	133.9	1.52	
01/05/05			26.2	190.8	134.1	2.24	
01/05/05			26.2	190.7	134.1	2.14	
01/05/05						1.98	
01/05/05						2.98	
01/05/05						3.34	
01/05/05						2.55	
01/05/05						2.22	
02/28/05	25.0	7.96	25.6	198.8	142.0	1.95	0.0197
02/28/05	25.0	7.95	25.6	197.5	144.0	2.26	
02/28/05	25.0	7.98	25.6	204.0	144.0	2.25	
02/28/05	25.0	7.91	25.6	204.0	143.0	2.18	
02/28/05	25.0	7.93	25.6	204.0	144.0	2.01	
02/28/05						1.60	
02/28/05						2.47	
02/28/05						2.52	
02/28/05						2.14	
02/28/05						2.12	
03/17/05	26.3	7.99	26.7	211.0	147.0	1.09	0.0255
03/17/05	26.3	7.98	26.7	211.0	148.0	1.18	
03/17/05	26.3	8.00	26.7	210.0	147.0	1.13	
03/17/05	26.3	7.99	26.7	211.0	144.0	1.07	
03/17/05	26.3	7.99	26.7	212.0	143.0	1.05	
03/17/05						1.18	
03/17/05						1.19	
03/17/05						1.18	
03/17/05						0.96	
03/17/05						1.05	
04/20/05	25.8	8.14	26.3	219.0	155.0	0.53	0.0350
04/20/05	25.8	8.07	26.3	218.0	154.0	0.48	
04/20/05	25.8	8.14	26.3	219.0	153.0	0.55	
04/20/05	25.8	8.12	26.3	219.0	155.0	0.85	
04/20/05	25.8	8.09	26.3	218.0	154.0	0.63	
04/20/05						0.49	
04/20/05						0.50	
04/20/05						0.45	
04/20/05						0.43	
04/20/05						0.56	

Site **Jc**
continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
05/10/05	28.5	8.00	29.0	225.0	151.0	2.45	0.0241
05/10/05	28.5	8.02	29.0	221.0	152.0	1.02	
05/10/05	28.5	7.98	29.0	222.0	149.0	1.67	
05/10/05	28.5	8.00	29.0	220.0	154.0	0.84	
05/10/05	28.5	7.99	29.0	220.0	150.0	3.38	
05/10/05						1.49	
05/10/05						2.08	
05/10/05						1.01	
05/10/05						2.07	
05/10/05						1.55	
05/20/05	24.6	7.88	25.2	100.2	69.5	694.00	1.2670
05/20/05	24.6	7.91	25.2	100.7	70.0	695.00	
05/20/05	24.6	7.72	25.2	100.3	70.5	708.00	
05/20/05	24.6	7.79	25.2	100.0	69.4	694.00	
05/20/05	24.6	7.92	25.2	100.7	69.3	694.00	
05/20/05						696.00	
05/20/05						683.00	
05/20/05						703.00	
05/20/05						681.00	
05/20/05						679.00	
06/02/05	26.0	8.23	26.6	147.6	102.6	20.80	0.5464
06/02/05	26.0	8.23	26.6	147.7	102.9	19.28	
06/02/05	26.0	8.25	26.6	147.7	103.1	19.20	
06/02/05	26.0	8.24	26.6	147.6	103.0	21.00	
06/02/05	26.0	8.24	26.6	147.1	102.5	19.16	
06/02/05						20.00	
06/02/05						20.10	
06/02/05						20.00	
06/02/05						20.10	
06/02/05						19.24	
07/08/05	25.2	8.11	25.7	111.7	77.9	16.74	1.0137
07/08/05	25.2	8.12	25.7	111.8	77.8	17.93	
07/08/05	25.2	8.13	25.7	111.1	77.7	16.93	
07/08/05	25.2	8.13	25.7	111.5	77.8	16.57	
07/08/05	25.2	8.10	25.7	111.9	77.9	15.39	
07/08/05						16.24	
07/08/05						15.63	
07/08/05						17.24	
07/08/05						16.62	
07/08/05						16.48	

Quebrada San Juan

Site **Ja**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
2/11/2005	23.0	8.01	23.6	207	144.6	0.99	
2/28/2005	26.0	7.97	26.5	212	148.0	1.49	0.0197
3/17/2005	27.3	7.82	27.7	218	151.4	0.98	0.0366
4/20/2005	26.9	8.03	27.5	220	154.0	1.58	0.0366
5/10/2005	29.4	8.18	29.7	223	157.8	4.94	0.0217
6/4/2005	26.1	8.21	26.6	184.1	129.5	5.65	0.4784
7/8/2005	25.6	8.07	26.1	120.5	84.5	20.2	1.1922
8/7/2005	25.4	7.92	25.9	145.4	102.3		0.4158

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
02/11/05	23.0	8.07	23.6	208.0	145.0	1.11	
02/11/05	23.0	7.99	23.6	204.0	143.0	1.12	
02/11/05	23.0	8.02	23.6	206.0	145.0	1.20	
02/11/05	23.0	8.00	23.6	208.0	145.0	0.87	
02/11/05	23.0	7.99	23.6	208.0	145.0	0.89	
02/11/05						1.01	
02/11/05						0.94	
02/11/05						1.01	
02/11/05						0.82	
02/11/05						0.91	
02/28/05	26.0	7.95	26.5	212.0	148.0	1.27	0.0197
02/28/05	26.0	7.96	26.5	212.0	148.0	1.58	0.0197
02/28/05	26.0	7.98	26.5	209.0	149.0	1.52	0.0197
02/28/05	26.0	7.96	26.5	212.0	148.0	1.50	0.0197
02/28/05	26.0	7.99	26.5	213.0	147.0	1.26	0.0197
02/28/05						1.63	0.0197
02/28/05						1.31	0.0197
02/28/05						1.62	0.0197
02/28/05						1.55	0.0197
02/28/05						1.65	0.0197

Site **Ja**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
03/17/05	27.3	7.81	27.7	218.0	151.0	1.41	0.0366
03/17/05	27.3	7.84	27.7	217.0	151.0	0.69	0.0366
03/17/05	27.3	7.83	27.7	219.0	152.0	1.51	0.0366
03/17/05	27.3	7.81	27.7	218.0	151.0	0.83	0.0366
03/17/05	27.3	7.83	27.7	218.0	152.0	0.67	0.0366
03/17/05						0.89	0.0366
03/17/05						1.28	0.0366
03/17/05						0.68	0.0366
03/17/05						1.07	0.0366
03/17/05						0.72	0.0366
04/20/05	26.9	8.02	27.5	220.0	153.0	1.94	0.0366
04/20/05	26.9	8.06	27.5	219.0	155.0	1.59	0.0366
04/20/05	26.9	8.03	27.5	222.0	154.0	1.36	0.0366
04/20/05	26.9	8.02	27.5	219.0	154.0	1.99	0.0366
04/20/05	26.9	8.01	27.5	222.0	154.0	1.41	0.0366
04/20/05						1.50	0.0366
04/20/05						1.36	0.0366
04/20/05						1.14	0.0366
04/20/05						2.16	0.0366
04/20/05						1.37	0.0366
05/10/05	29.4	8.20	29.7	223.0	158.0	4.42	0.0217
05/10/05	29.4	8.19	29.7	222.0	157.0	3.85	0.0217
05/10/05	29.4	8.19	29.7	223.0	158.0	3.85	0.0217
05/10/05	29.4	8.17	29.7	223.0	158.0	5.02	0.0217
05/10/05	29.4	8.16	29.7	224.0	158.0	5.46	0.0217
05/10/05						5.78	0.0217
05/10/05						3.85	0.0217
05/10/05						6.28	0.0217
05/10/05						5.28	0.0217
05/10/05						5.58	0.0217
06/04/05	26.1	8.19	26.6	184.4	129.4	5.16	0.4784
06/04/05	26.1	8.20	26.6	184.5	129.5	5.25	0.4784
06/04/05	26.1	8.22	26.6	183.9	129.5	4.99	0.4784
06/04/05	26.1	8.21	26.6	184.0	129.5	6.27	0.4784
06/04/05	26.1	8.21	26.6	183.9	129.5	5.98	0.4784
06/04/05						5.97	0.4784
06/04/05						5.83	0.4784
06/04/05						5.63	0.4784
06/04/05						5.72	0.4784
06/04/05						5.68	0.4784

Site **Ja**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
07/08/05	25.6	8.08	26.1	120.4	84.1	21.3	1.1922
07/08/05	25.6	8.06	26.1	120.9	84.3	21.4	1.1922
07/08/05	25.6	8.01	26.1	121.1	84.7	18.4	1.1922
07/08/05	25.6	8.11	26.1	120.2	84.7	20.4	1.1922
07/08/05	25.6	8.07	26.1	120.1	84.5	18.6	1.1922
07/08/05						20.0	1.1922
07/08/05						19.8	1.1922
07/08/05						21.5	1.1922
07/08/05						20.6	1.1922
07/08/05						20.5	1.1922
08/03/05	25.4	7.89	25.9	145.4	102.3		0.4158
08/03/05	25.4	7.90	25.9	145.8	102.4		0.4158
08/03/05	25.4	7.91	25.9	145.3	102.5		0.4158
08/03/05	25.4	7.97	25.9	144.9	101.9		0.4158
08/03/05	25.4	7.92	25.9	145.8	102.4		0.4158

El Corpus drainage

Site **Jb**

Summary

date	temppH	pH	tempcond	cond	ppm	turb	flow
11/17/2004	24.0	7.74					
12/16/2004	24.3	7.41	24.6	362	253	1.49	
3/4/2005	30.6	8.35	31.1	418	292	6.01	
3/30/2005	32.1	8.57	32.6	330	230	2.74	0.0000
4/18/2005	25.8	7.08	26.3	444	308	2.43	0.0000
5/20/2005	24.6	8.06	25.2	168.2	117.4	145.70	0.4886
6/5/2005	25.5	7.95	26.0	190.2	132.8	14.67	0.1885
6/29/2005	24.5	8.04	25.0	194.0	135.3	3.45	0.1505
8/3/2005	25.5	7.62	26.0	241	167.6		0.0785

All measurements

date	temppH	pH	tempcond	cond	ppm	turb	flow
11/17/04	23.4	7.79					
11/17/04	23.5	7.73					
11/17/04	23.6	7.76					
11/17/04	23.8	7.75					
11/17/04	24.0	7.68					

Site **Jb**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
12/16/04	24.3	7.40	24.6	361	254	1.29	
12/16/04	24.3	7.41	24.6	362	253	1.50	
12/16/04	24.3	7.43	24.6	362	252	1.43	
12/16/04						1.69	
12/16/04						1.45	
12/16/04						1.72	
12/16/04						1.38	
12/16/04						1.50	
12/16/04						1.46	
12/16/04						1.51	
03/04/05	30.6	8.34	31.1	419	293	5.92	0.000077
03/04/05	30.6	8.32	31.1	418	291	5.93	
03/04/05	30.6	8.37	31.1	417	292	5.94	
03/04/05	30.6	8.36	31.1	419	293	5.98	
03/04/05	30.6	8.38	31.1	419	291	6.15	
03/04/05						6.59	
03/04/05						6.26	
03/04/05						5.99	
03/04/05						5.58	
03/04/05						5.73	
03/30/05	32.1	8.58	32.6	331	231	2.86	0.000046
03/30/05	32.1	8.56	32.6	330	230	3.06	
03/30/05	32.1	8.55	32.6	331	230	2.46	
03/30/05	32.1	8.59	32.6	328	231	2.25	
03/30/05	32.1	8.56	32.6	331	230	3.28	
03/30/05						3.58	
03/30/05						2.84	
03/30/05						2.49	
03/30/05						2.25	
03/30/05						2.33	
04/18/05	25.8	7.05	26.3	443	309	2.55	0.000009
04/18/05	25.8	7.12	26.3	445	306	2.34	
04/18/05	25.8	7.06	26.3	447	307	2.32	
04/18/05	25.8	7.09	26.3	442	309	2.31	
04/18/05	25.8	7.07	26.3	443	307	2.41	
04/18/05						2.27	
04/18/05						2.45	
04/18/05						2.63	
04/18/05						2.78	
04/18/05						2.27	

Site **Jb**
Continued

date	temppH	pH	tempcond	cond	ppm	turb	flow
05/20/05	24.6	8.06	25.2	168.1	117.2	144	0.488600
05/20/05	24.6	8.05	25.2	168.3	117.3	145	
05/20/05	24.6	8.04	25.2	168.2	117.6	144	
05/20/05	24.6	8.06	25.2	167.9	117.2	149	
05/20/05	24.6	8.05	25.2	168.5	117.8	148	
05/20/05						144	
05/20/05						144	
05/20/05						144	
05/20/05						148	
05/20/05						147	
06/05/05	25.5	7.92	26.0	189.9	132.7	16.18	0.188500
06/05/05	25.5	7.85	26.0	190.0	132.6	13.79	
06/05/05	25.5	7.99	26.0	190.6	132.5	14.79	
06/05/05	25.5	8.01	26.0	190.2	133.0	15.06	
06/05/05	25.5	7.96	26.0	190.4	133.1	14.32	
06/05/05						14.43	
06/05/05						13.36	
06/05/05						15.29	
06/05/05						14.50	
06/05/05						14.94	
06/29/05	24.5	8.05	25.0	193.9	135.5	3.29	0.150500
06/29/05	24.5	7.99	25.0	193.8	135.6	3.28	
06/29/05	24.5	8.03	25.0	193.8	134.9	3.91	
06/29/05	24.5	8.05	25.0	194.4	135.0	3.32	
06/29/05	24.5	8.06	25.0	194.3	135.3	3.72	
06/29/05						3.32	
06/29/05						3.42	
06/29/05						3.35	
06/29/05						3.47	
06/29/05						3.43	
08/03/05	25.5	7.66	26.0	240	168.0		0.078500
08/03/05	25.5	7.65	26.0	241	168.0		
08/03/05	25.5	7.58	26.0	240	167.0		
08/03/05	25.5	7.59	26.0	241	167.0		
08/03/05	25.5	7.61	26.0	241	168.0		

Appendix 2: Laboratory results

All analyses performed at the *Laboratorio de Calidad de Agua, Aguas de Choluteca.*

N/A indicates no value reported
Inc. indicates "uncountable" number of bacteria (number >200)
***** indicates value deemed an obvious outlier and was discarded
****** indicates value is believed to be in error, but falls within possible range of values
******* indicates samples taken closely following rain event

Quebrada San Juan

Site	Date (2005)	Sample No.	Fecal Coliforms (per 100ml)	Total Coliforms (per 100ml)	pH	Turbidity (NTU)	Conductivity (µS/cm)	Ammonium (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)	Sulfates (mg/L)	Aluminum (mg/L)	Phosphates (mg/L)	Total Iron (mg/L)	Chlorides (mg/L)	Fluoride (mg/L)	Manganese (mg/L)	Hardness (mg/L)	TDS (mg/L)
Je	5/19	1	2	2	7	2	147	0	0	1.5	8	0	0.6	0	N/A	N/A	0	54	92.6
Je	5/19	2	2	2	7	3	146	0	0	1.4	12	0	0.6	0	N/A	N/A	0	52	91.7
Je	5/19	3	1	2	7	3	145	0	0	1.6	12	0	0.6	0	N/A	N/A	0	54	91.4
Jd	6/10***	1	Inc.	Inc.	7	18	110	0	0	1	*	0	0.5	0	N/A	N/A	0	40	69
Jd	6/10***	2	Inc.	Inc.	7	19	110	0	0	1.1	*	0	0.5	0	N/A	N/A	0	40	69
Jd	6/10***	3	Inc.	Inc.	7	19	109	0	0	1.4	*	0	0.4	0	N/A	N/A	0	40	69
Jc	4/20	1	Inc.	Inc.	7	2	210	0	0	1.8	11	0	0.44	0	N/A	N/A	0	42	132
Jc	4/20	2	Inc.	Inc.	7	2	207	0	0	1.8	16	0	*	0	N/A	N/A	0.2	40	130
Jc	4/20	3	Inc.	Inc.	7	2	208	0	0	1.3	10	0	*	0	N/A	N/A	0	41	131
Ja	5/10	1	Inc.	Inc.	7	4	213	0	0	1.2	24**	0	0.5	0	N/A	N/A	0	84	134
Ja	5/10	2	Inc.	Inc.	7	4	213	0	0	1.3	11	0	0.5	0	N/A	N/A	0	82	134
Ja	5/10	3	Inc.	Inc.	7	5	213	0	0	1.4	9	0	0.5	0	N/A	N/A	0	86	135

El Corpus drainage

Site	Date (2005)	Sample No.	Fecal Coliforms (per 100ml)	Total Coliforms (per 100ml)	pH	Turbidity (NTU)	Conductivity (µS/cm)	Ammonium (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)	Sulfates (mg/L)	Aluminum (mg/L)	Phosphates (mg/L)	Total Iron (mg/L)	Chlorides (mg/L)	Fluoride (mg/L)	Manganese (mg/L)	Hardness (mg/L)	TDS (mg/L)
Jb	4/18	1	N/A	N/A	7	2	459	0	0	3.9	150	0	0.3	0	N/A	N/A	0	82	289
Jb	4/18	2	Inc.	Inc.	7	3	450	0	0	4.4	150	0	0.4	0	N/A	N/A	0	82	284
Jb	4/18	3	Inc.	Inc.	7	5	449	0	0	4.2	37**	0	0.4	0	N/A	N/A	0	82	283

Río Calderas

Site	Date (2005)	Sample No.	Fecal Coliforms (per 100ml)	Total Coliforms (per 100ml)	pH	Turbidity (NTU)	Conductivity (µS/cm)	Ammonium (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)	Sulfates (mg/L)	Aluminum (mg/L)	Phosphates (mg/L)	Total Iron (mg/L)	Chlorides (mg/L)	Fluoride (mg/L)	Manganese (mg/L)	Hardness (mg/L)	TDS (mg/L)
Cc	6/29		58	Inc.	7	14	88	0	0	2.1	0	0	0.6	0.1	N/A	N/A	0	30	55
Cc	7/13		N/A	N/A	8	5	86	0	0	1.1	1	0	0.1	0	N/A	N/A	0.2	38	54
Cc	7/28		16	25	N/A	6	124	0.1	0	1.5	*	0.1	0.2	0	N/A	N/A	0.4	*	78
Cb	6/29		35	Inc.	7	6	116	0	0	2.7	17	0	0.3	0	N/A	N/A	0	35	73
Cb	7/13		N/A	N/A	8	7	95	0	0	1.2	9	0	0.2	0	N/A	N/A	0.1	35	60
Cb	7/28		28	30	N/A	6	157	0	0	1.5	17	0	0.2	0	N/A	N/A	0.4	*	99
Ca	3/29	1	5	8	7	0	205	0	0	1.8	9	0	0.3	0	15	0	0	84	129
Ca	3/29	2	6	10	7	0	203	0	0	1.2	12	0	0.4	0	14	0	0	80	129
Ca	3/29	3	8	10	7	1	202	0	0	1.2	11	0	0.2	0	16	0	0	82	130

Quebrada El Sabroso

Site	Date (2005)	Sample No.	Fecal Coliforms (per 100ml)	Total Coliforms (per 100ml)	pH	Turbidity (NTU)	Conductivity (µS/cm)	Ammonium (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)	Sulfates (mg/L)	Aluminum (mg/L)	Phosphates (mg/L)	Total Iron (mg/L)	Chlorides (mg/L)	Fluoride (mg/L)	Manganese (mg/L)	Hardness (mg/L)	TDS (mg/L)
Sc	7/26	1	Inc.	Inc.	N/A	2	159	0	0	0.2	60	0	0.2	0	N/A	N/A	0	40	100
Sc	7/26	2	Inc.	Inc.	N/A	1	155	0	0	0.1	58	0	0.1	0.1	N/A	N/A	0.1	42	97
Sc	7/26	3	Inc.	Inc.	N/A	1	157	0	0	0.1	60	0	0.2	0.1	N/A	N/A	0.1	40	99
Sb	7/19	1	N/A	N/A	8	17	251	0.1	0	1.5	53	0	0.1	0.1	N/A	N/A	0	120	158
Sb	7/19	2	N/A	N/A	8	29	250	0.1	0	1.5	98	0	0.4	0	N/A	N/A	0	119	157
Sb	7/19	3	N/A	N/A	8	25	250	0.1	0	0.3	97	0	0.4	0	N/A	N/A	0	122	157
Sa	6/29		6	Inc.	7	13	246	0	0	2.1	69	0	0.4	0.1	N/A	N/A	0	100	158
Sa	7/13		N/A	N/A	8	6	201	0	0	1.5	34	0	0.2	0	N/A	N/A	0.1	100	126
Sa	7/28		54	Inc.	N/A	6	278	0	0	5.9	86	0.5	0.2	0	N/A	N/A	0.4	N/A	175

Appendix 3: DEFOMIN reports

March 2004

DIRECCIÓN EJECUTIVA DE FOMENTO A LA MINERIA
DEFOMIN

DEPARTAMENTO DE CONTROL AMBIENTAL

INFORME DE MONITOREO AMBIENTAL
MINA CLAVO RICO
FECHA DE INSPECCION: 18 AL 20 DE FEBRERO DE 2004

TEGUCIGALPA M.D.C. 5 DE MARZO DE 2004

DEPARTAMENTO DE LABORATORIO
DEFOMIN

ANALISIS DE MUESTRAS

PROYECTO MINERO:	*Clavo Rico*
Fecha Toma de muestras:	*19 de febrero*
REALIZADO POR:	*Ing. Raul Edgardo Del Cid*
FECHA DE ENTREGA:	*3/01/04*

IDENTIFICACION DE LA MUESTRA			Mn	Zn	Cu	Ni	Pb	Hg	Cd	Cr T	As	Al	Ag	Fe	Se	CN	Parametros de Campo: Hora	Vol/ml	pH	Tm C	Ta C	Cond.
1,2	PACR	Pozo de Agua Clavo Rico	0.11	0.21	N	N	N	N	N	N		N	N	0.13	N	N	10;04	500	7.05	23.3	27	58.3
3	NAP	nacimiento debajo del pozo	2.68	0.75	3.64	N	N	N	N	N		63.24	N	37.62	N		10:25	500	3.18	24.9	27	172
4,5	QSDT	quebrada el sabroso despues tributario	N	0.78	N	N	N	N	N	N		0.32	N	N	N	N	11:12	500	6.91	25	28	45.1
6,7	QSAT	Q. El Sabroso antes tributario	0.82	0.78	N	N	N	N	N	N		N	N	N	N	N	11:42	500	7.7	25.3	28	35
8,9	QSDT 1	quebrada el sabroso abajo tributario	N	0.49	0.86	N	N	N	N	N		16.70	N	0.27	N	N	11:58	500	6.1	25.2	29	53.9

SOLICITADO POR: Departamento de Contro

Firma realizado	
V.B jefe departamento	

INDICADOR

N_T	Nitrogeno total
F_T	Fosforo total
Cr_T	Cromo Total
Fl	Fluoruro
Tm	Temperatura de la muestra
Ta	Temperatura ambiente
SS	Solidos Sedimentables
Ssus.	Solidos Suspendidos

RESULTADO DE ANÁLISIS DE LAS MUESTRAS DE AGUA SUPERFICIAL.

Las muestras tomadas fueron analizadas para metales totales, se recolectaron muestras superficiales. Los elementos analizados fueron los siguientes:

Manganeso
Zinc
Cobre
Níquel
Plomo
Mercurio
Cadmio
Cromo
Aluminio
Plata
Hierro
Selenio
Cianuro

Al comparar los resultados de análisis de la gira anterior con la actual se observa que se mantienen en el punto del pozo de agua Clavo Rico, a excepción del hierro que tuvo una ligera disminución de 0.9 ppm, a 0.13 ppm. En el nacimiento de agua abajo de pozo hay concentraciones de metales como ser: Manganeso 2.68 ppm, Zinc 0.75, Cobre 3.64 ppm, Aluminio 63.24 ppm, Hierro 37.62 ppm, para este punto no se monitoreo en la gira pasada por lo que no se puede hacer una comparación de las concentraciones, este punto se hará un control mas riguroso para ver su comportamiento en las próximas visitas. Para el punto Quebrada El Sabroso abajo de la confluencia con el tributario los parámetros analizados se mantienen sin cambios, algo importante que hay que mencionar es la presencia de Aluminio con una concentración de 16.70 ppm, esta muestra se tomo aproximadamente unos 15 m abajo de la confluencia con el tributario (QSDT1) agua proveniente del nacimiento abajo de pozo, este punto al igual que el nacimiento se mantendrá bajo un control mas riguroso. En la Quebrada El Sabroso antes de la confluencia con el tributario (nacimiento), los elementos analizados se mantienen en relación con los resultados de la inspección anterior a excepción del Manganeso 0.82 ppm y Zinc 0.78 ppm que sufrieron un ligero incremento. El elemento cianuro no se detecto en ninguno de los puntos monitoreados.

DIRECCIÓN EJECUTIVA DE FOMENTO A LA MINERIA
DEFOMIN

DEPARTAMENTO DE CONTROL AMBIENTAL

INFORME DE MONITOREO AMBIENTAL
MINA CLAVO RICO
FECHA DE INSPECCION: 30 DE AGOSTO AL 3 DE SEPTIEMBRE DE 2004

TEGUCIGALPA M.D.C.

27 SEPTIEMBRE DE 2004

DEPARTAMENTO DE LABORATORIO
DEFOMIN

ANALISIS DE MUESTRAS

PROYECTO MINERO:	*Clavo Rico*
solicitud de analisis	*13/09/04*

Realizado Por	*Ing. Claudia Torres*
Fecha de Entrega	*16/09/04*

IDENTIFICACION DE LA MUESTRA			Mn	Zn	Cu	Ni	Pb	Hg	Cd	Cr T	As	Al	Fe	Se	CN	Parametros de Campo: Hora	Vol/ml	pH	Tm C	Ta C	Cond.	Observacion
1,2	PACR	Pozo de Agua Clavo Rico	0.15	0.11	N	0.01	N	N	N	N	0.006 *	0.11	0.39	N	N	8:50	500	7.50	25.6	27		
3,4	NAP + EI	nacimiento debajo del pozo + escorrentilla de Invierno	2.34	0.39	3.30	0.05	N	N	N	0.01	0.007 *	65.40	56.30	N	N	9:15	500	2.75	25.8	27		
5,6	EI	Escorrentilla de Invirno	2.42	0.56	5.90	0.07	N	N	N	N	0.005 *	110.4	61.10	N	N	9:40	500	2.55	26.7	27		
7,8	QECH	Quebrada El Chaguite	2.47	0.39	3.40	0.06	N	N	N	0.02	N	69.60	44.40	N	N	10:00	500	2.85	25.6	27		
9,10	QSAT	Q. El Sabroso antes tributario	N	1.64	0.02	0.01	0.06	N	N	N	N	0.15	N	N	N	10:20	500	8.08	26	27		
11,12	QSDT 1	quebrada el sabroso abajo tributario	0.33	0.65	0.34	0.01	0.03	N	N	N	N	7.67	N	N	N	11:00	500	6.26	25.6	29		
13,14	QSDT	quebrada el sabroso despues tributario	0.08	0.09	0.07	0.02	N	N	N	N	N	0.66	N	N	N	11:20	500	7.15	25.4	29		
15,16	ADM	Agua de Mina	2.54	1.12	40.00	0.29	N	N	N	N	0.51	836.0	5990	N	N	8:40	500	2.05	24.5	28		

SOLICITADO POR: Departamento de Contr

Firma realizado	
V.B jefe departamento	

INDICADOR

N_T	Nitrogeno total
F_T	Fosforo total
Cr_T	Cromo Total
Fl	Fluoruro
Tm	Temperatura de la muestra
Ta	Temperatura ambiente
SS	Solidos Sedimentables
Ssus.	Solidos Suspendidos

DIRECCION EJECUTIVA DE FOMENTO A LA MINERIA LABORATORIO HONDURAS