A Valuation Analysis of the Role of Cloud Forests In Watershed Protection

Sierra de las Minas Biosphere Reserve, Guatemala
and
Cusuco National Park, Honduras

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by

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August 1996

A collaborative research project conducted by the RARE Center for Tropical Conservation, the Fundación Defensores de la Naturaleza and the Fundación Ecologista "Hector Rodrigo Pastor Fasquelle" (Honduras) with support from The Nature Conservancy, the U.S. Agency for International Development, the Moriah Fund and the U.S. State Department OES – ETC.

EXECUTIVE SUMMARY

In the Neotropics, cloud forests are the guardians of Latin America's water supply. Frequently envelopped in clouds and bathed in mist, these forests capture tiny fog droplets that condense on the vegetation through a process called "horizontal precipitation," that has been shown to add "extra" water to the hydrologic cycle not quantified by standard precipitation gauges. It is also believed that cloud forests play a very significant role in the temporal regulation of streamflow and maintenance of dry season flow.

Horizontal precipitation has been shown to be quite site-specific and often seasonal. Research in several tropical countries indicates that this fog drip can represent at least 5% and sometimes 45% or more of total rainfall (Bruijnzeel 1990; Weaver 1972; Stadtmüller and Agudelo 1990) and that it often occurs during the dry season and even on days without rainfall. Although very little research has been done in this area, deforestation of montane cloud forests has been shown to decrease streamflow during the dry season (Harr 1980), due to the loss of horizontal precipitation and decrease in soil infiltration capacity.

However, despite the hydrologic value of these areas, cloud forests represent one of the world's most threatened forest ecosystems; all tropical montane forests are being lost approximately 30% faster than lowland tropical forests, most frequently through conversion to agricultural areas (Doumenge et al. 1993). Even if allowed to regenerate, these fragile ecosystems, characterized by low soil fertility, low temperatures and slow growth rates, are estimated to need approximately two centuries to fully regenerate (Weaver 1990).

The RARE Center for Tropical Conservation has collaborated with the Fundación Defensores de la Naturaleza and the Fundación Ecologista "Hector Rodrigo Pastor Fasquelle" to conduct valuation research to quantify the hydrologic and socioeconomic benefits of cloud forests in the Sierra de las Minas Biosphere Reserve (SMBR), in Guatemala, and Cusuco National Park, in Honduras. The four major research objectives were to quantify horizontal precipitation in the cloud forests of each reserve, to evaluate the influence of forest cover on streamflow, to quantify the socioeconomic value of water flowing from the southern side of the SMBR to the arid Motagua Valley, and to predict the hydrologic and socioeconomic effects of deforestation in this region.

Research conducted in six sites determined that horizontal precipitation occurs in windward and high-altitude leeward areas during the dry season, when water supply is most critical in the Motagua Valley. However, it does not increase total precipitation at a statistically significant level. Paired basin research suggested that fog drip may be far less significant for the maintenance of dry season flow than the role of forest soils in storing moisture and maintaining groundwater flow during dry periods. In the two paired basin experiments, dry season baseflow was at least twice as high in the forested basins than the deforested ones.

In the Motagua Valley, irrigation is the base of the agricultural economy. In the two study watersheds on the southern side of the SMBR (Jones and Hato), during the driest months of the year, up to 80-95% of streamflow is utilized for irrigation. A survey in these watersheds indicated that irrigated pasture is 7 to 28 times as productive as dry (rain-fed) pasture, that perennial agriculture is approximately 6 times as productive on irrigated land as on dry land, and that irrigation allows the cultivation of more valuable crops (such as non-traditional export crops) that could not be grown on dry land. Although irrigated land in the Jones basin represented only 30% of all agricultural land and pasture, it produced 90% of all agricultural profits in the basin in 1994-95.

The hydrologic and socioeconomic data from these two watersheds were used to construct a model to simulate the change in land use and agricultural productivity that would result from changes in the river flow that is utilized for irrigation, due to deforestation. In the Jones watershed, the model predicted that if 20% of remaining forest cover were cut, approximately 88 ha. of irrigated land would have to be converted to rain-fed agriculture or taken out of production, causing a loss of $52,000 in annual net profits. Economic losses would not be as high in the Hato basin, where 30% deforestation was predicted to take 35 ha. out of production, at an annual cost of $15,160. The economic impact of deforestation could be most severe in the middle of the Hato watershed, where farmers own an average of only 0.66 ha. of irrigated land and 1.27 ha. of dry land.

Additional socioeconomic research explored the value of water from the SMBR for small-scale hydropower, industrial use and domestic supply. Small-scale hydropower produces valuable electricity for several families in the headwaters of the Hato basin, where connecting houses to the national energy grid would be prohibitively expensive. A survey of the largest industrial water users in the Motagua Valley indicated that this water use is completely unregulated, and none of companies are taking any measures to protect future water resources, although in several cases water is the base upon which they are making profits. Finally, interviewing women throughout the Jones watershed provided information about domestic water supply issues. Many of the communities located in close proximity to the abundant water resources of the SMBR experience frequent cutoffs in domestic water supply, due to inadequate infrastructure.

In conclusion, water clearly represents one of the foundations of the rural economy in the arid Motagua Valley, primarily due to irrigation. The maintenance of dry season flow used for irrigation depends on cloud forest and watershed conservation for the protection of both infiltration capacity and horizontal precipitation, with the former being more important than the latter. Such forest protection depends on the development of economic alternatives to unprofitable and unsustainable traditional agriculture in marginal areas and more efficient management of water resources. It is recommended that watershed management organizations be formed, to translate environmental awareness into collaborative action. Watershed protection should be promoted through the development of incentives for economic development, and a direct link should be established between water use (agricultural, industrial or domestic) and maintenance of the resource. Finally, further research should be conducted on the hydrologic effects of deforestation, and research should be initiated to examine the ecological impact of water diversion.

DEDICATION

To the many individuals who have committed their lives to protecting the magnificent natural heritage of Central America, may your vision and love for the land continue to inspire others and generate change.

To the spectacular rivers that flow from the hills of the Sierra and Cusuco, that they may flow clear and full forever.

To the enchanted forests that blanket these hills, bathed in mist and bursting with life, may your splendour touch the hearts and souls of many, many generations to come.

ACKNOWLEDGEMENTS

The principal author would like to express special gratitude to two people who have been an invaluable source of inspiration and support during this research. To Alvaro Molina, whom life has given me the great fortune to meet and love, thank you for your *joie de vivre*, your commitment to the people and culture of Mesoamerica, patience and integrity. To George Powell, thank you for having the vision and persistence to make this project possible, for serving as a role model in your untiring dedication to the conservation of natural areas, for sharing ideas and giving encouragement and, most of all, for your friendship.

Many individuals and organizations contributed to this project. Most of the research funding was obtained through the Latin American Division of The Nature Conservancy, with the assistance of Anne McEnany, Kathy Moser and others. Funding was generously provided by the U.S. State Department, the Moriah Fund and the U.S. Agency for International Development. Laurie Hunter and Christine Psomiades of RARE and the staff of Defensores and the Fundacion Ecologista all contributed significantly to the administration of the funds.

Nelson Agudelo, Bruce Aylward, Alan González, Jaime Echeverría, Jorge Fallas, Peter Weaver and Frank Scatena provided valuable ideas and information. The Center for Sustainable Development Studies of the School for Field Studies allowed Professor Bernardo Aguilar to conduct analyses for the project on a voluntary basis. Dr. Robert Klein and Sergio Garcia of the Guatemalan office of the U.S. Center for Disease Control (CDC) and Professor Margarita Selle of the Universidad del Valle generously loaned computer equipment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: PROJECT OVERVIEW AND OBJECTIVES

1.1 BACKGROUND

In the communities surrounding several of the high peaks of Honduras, a legend exists that a mysterious enchanted lake can be found hidden in the tops of the mountains (Paz 1972). This legend is used to explain the numerous large rivers that flow down the hills from these peaks, supplying abundant water resources to the region's inhabitants. In reality, at the top of these high mountains it is not lakes that supply this water, but rather cloud forests that receive large quantities of rain, capture tiny fog droplets, and maintain a constant flow of water throughout the year.

By serving as living barriers in the aerial circulation of clouds, the trees and other vegetation in cloud forests capture mist, or what is called "horizontal precipitation," which is believed to add significant quantities of water to the hydrologic cycle. Although this topic has not been thoroughly investigated, research in Puerto Rico, Honduras and other tropical countries indicates that horizontal precipitation can represent between 4% and 45% of total rainfall (Bruijnzeel 1990; Weaver 1972; Stadtmüller and Agudelo, 1990). Because fog precipitation often occurs on days without rainfall, these forests also play a significant role in the regulation of the flow regime, especially during dry periods, and in reducing evapotranspiration rates (Zadroga, 1981).

Protection of cloud forests is extremely significant for the protection of water quantity and the temporal regulation of flow. Although numerous watershed studies conducted in temperate regions influenced by normal atmospheric conditions have shown that elimination of forest cover causes an increase in streamflow, caused by reduced evapotranspiration, deforestation of montane cloud forests can cause substantial decreases in water yield and increases in the number of low flow days in summer (Harr, 1980).

However, in spite of their clear hydrologic significance, cloud forests represent one of the world's most threatened ecosystems (Hamilton et al. 1993). Although they are often provided legal protection, their existence is continually at risk due to expansion of the agricultural frontier, illegal timber extraction, and a lack of appreciation for the socioeconomic benefits that they provide to their region's inhabitants.

The RARE Center for Tropical Conservation has collaborated with the Fundación Defensores de la Naturaleza (Defensores) and the Fundación

Ecologista "Hector Rodrigo Pastor Fasquelle" (Fundación Pastor) to conduct research to quantify the hydrologic and economic benefits of cloud forests in the Sierra de las Minas Biosphere Reserve (SMBR), in Guatemala, and Cusuco National Park, in Honduras.

The Sierra de las Minas Biosphere Reserve encompasses the watersheds of 63 permanent rivers, making it the largest producer of water in Guatemala. The socioeconomic value of the water resources of the Sierra strongly influenced the decision to establish the reserve in 1990. In this region, surface water determines economic relations, settlement patterns, land use, and agricultural productivity, particularly in the semi-arid valleys of Motagua and San Jerónimo, that receive annual precipitation as low as 500 mm.. As shown in Figure 1.1, these regions are naturally dry forest and thorny scrub vegetation regions, due to the rain shadow effect of the Sierra. Legal rights to water and irrigation lands provide motivation for permanent conflicts between upland inhabitants and those in the valley, as much for water quality as quantity. Local residents believe that streamflow has decreased dramatically during the past 10 years and that this situation is currently worsening.

In Honduras, Cusuco National Park, which is located within the Merendón mountain range, is hydrologically very significant for the Sula, Cuyamel and Naco valleys that surround it, where the major agricultural and industrial production of the country is concentrated. San Pedro Sula represents one of the most rapidly growing cities in Central America, both demographically and economically. This growth inevitably results in increasing demand for water, which originates in the Merendón mountain range. Although the water supplies for the city are located below the park, it is believed that Cusuco National Park plays a very significant role in overall water production and watershed regulation. As shown in Figure 1.2, Cusuco protects the headwaters of eleven major watersheds. The cloud forest maintains humidity throughout the year, while the valley has a dry season of at least three months.

1.2 OBJECTIVES

In order to justify the protection of these areas in quantitative, scientific and economic terms, and to be able to make crucial decisions about the management of these areas, research has focused on defining the hydrologic impact of forest cover in both reserves and quantifying the uses of the water and its economic, political and social value for local communities on the southern side of the

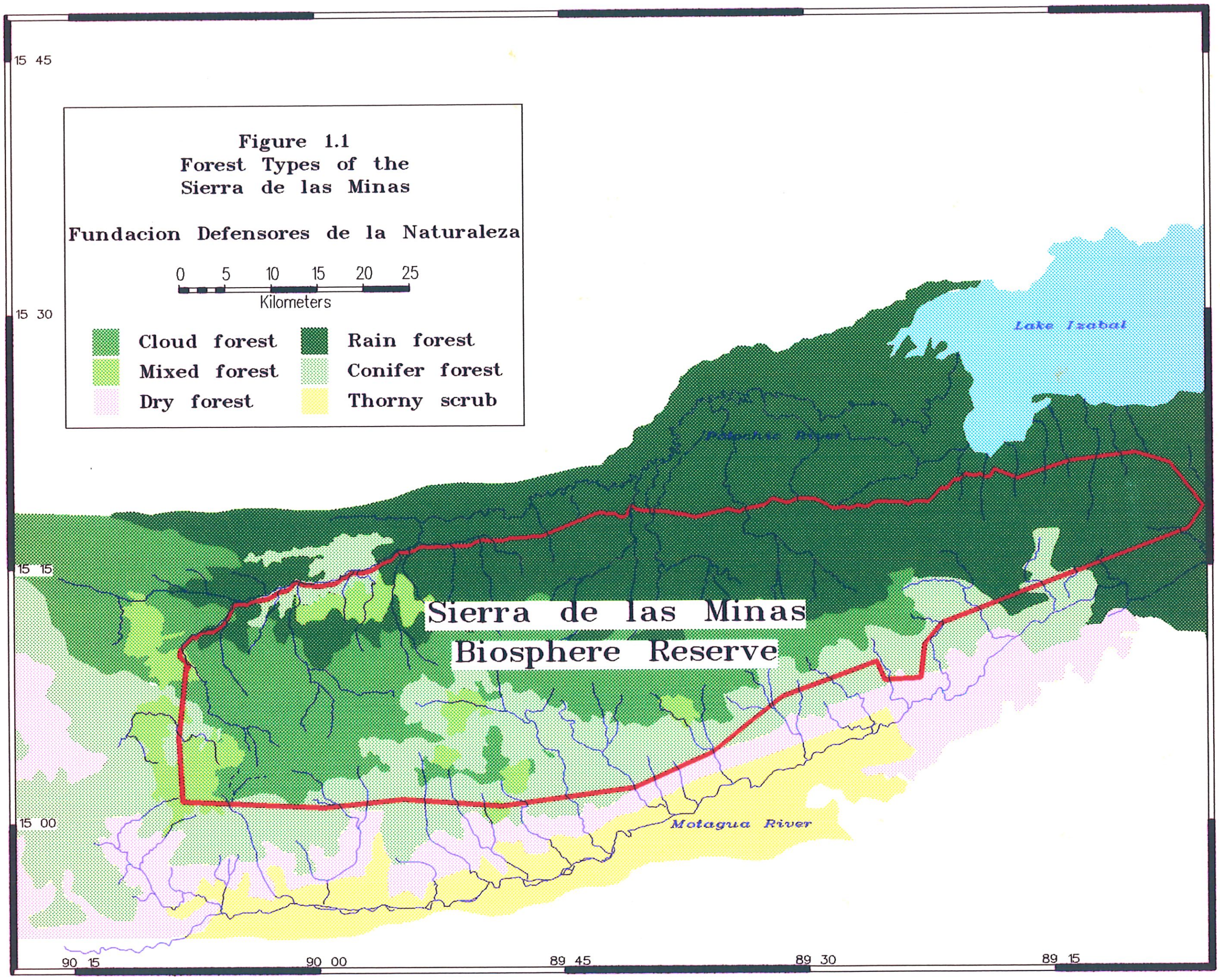


Figure 1.1
Forest Types of the Sierra de las Minas

Fundacion Defensores de la Naturaleza

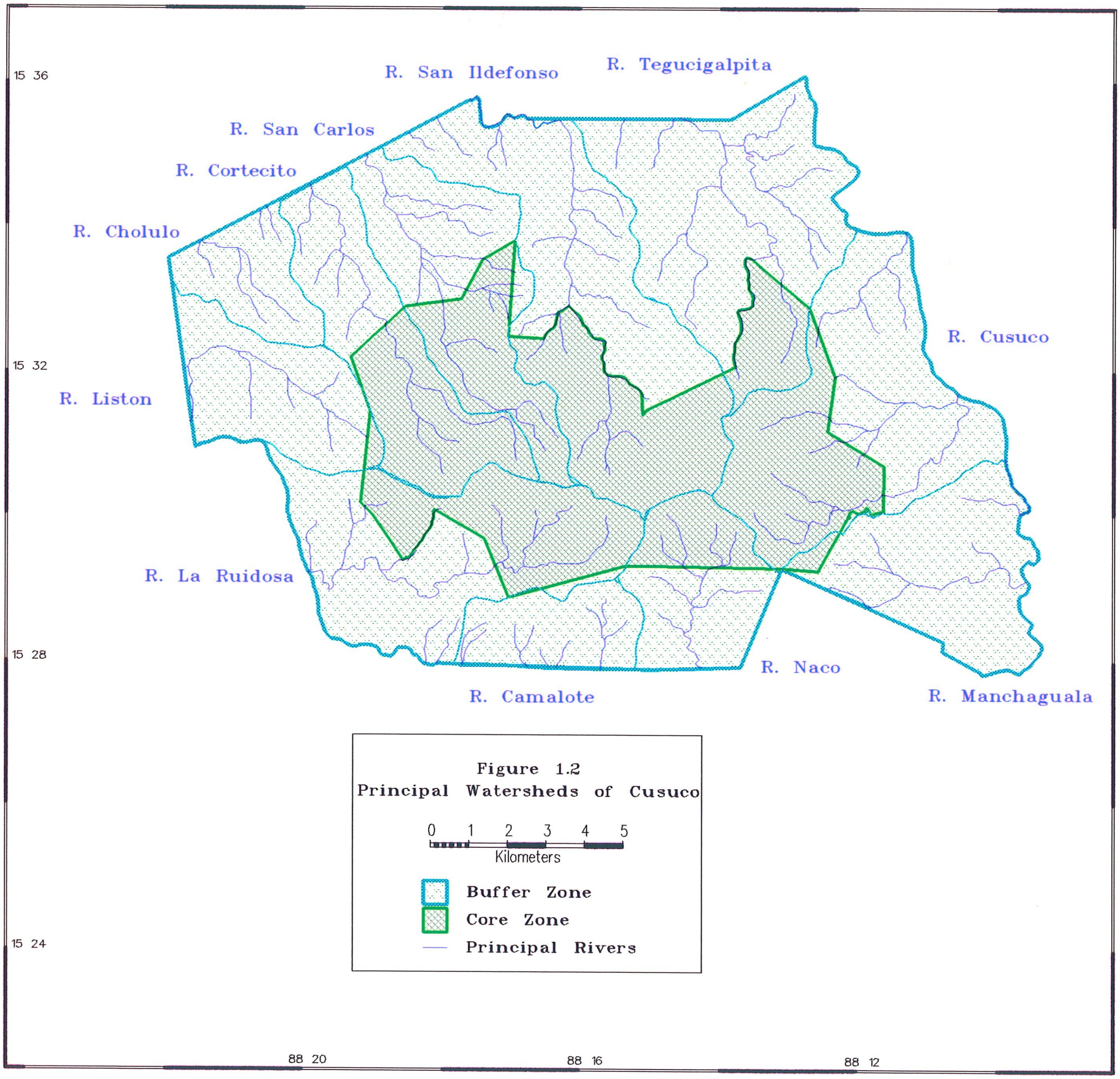


Figure 1.2
Principal Watersheds of Cusuco

Sierra, in the arid Motagua Valley. The four major research objectives are:

1. to quantify horizontal precipitation in the cloud forests of each reserve, and evaluate the influence of geographic location and altitude on horizontal precipitation;
2. to evaluate the influence of forest cover on streamflow;
3. to quantify the socioeconomic value of water flowing from the southern side of the Sierra de las Minas, for irrigation, small-scale hydropower generation, industrial use and domestic supply; and
4. to predict the hydrologic and socioeconomic effects of deforestation.

1.3 ORGANIZATION OF REPORT

The research has taken an interdisciplinary approach, combining an examination of the biophysical aspects of cloud forest hydrology with an economic valuation analysis. Chapter 2 reviews the literature in both of these areas, to provide the theoretical base upon which the research was developed. Chapter 3 provides background information on both the Sierra de las Minas Biosphere Reserve and Cusuco National Park. Chapter 4 describes both the hydrologic and socioeconomic methodologies.

Results are discussed in chapters 5-8. Chapters 5 provides the hydrologic results, including a quantification of horizontal precipitation and an examination of the relationship between forest cover and streamflow in two sets of paired basins. Chapter 6 defines the dynamics of irrigation in the two study watersheds on the southern side of the Sierra and presents the results of an agricultural productivity analysis used to determine the socioeconomic value of water used for irrigation. Chapter 7 describes a model built to combine the biophysical and socioeconomic data to simulate the effects of deforestation on irrigated agriculture in the study watersheds. Chapter 8 discusses three short analyses that focus on the socioeconomic value of water for small-scale hydropower, industrial use and domestic supply. Finally, Chapter 9 summarizes the major conclusions and recommendations.

CHAPTER 2: THE HYDROLOGIC AND SOCIOECONOMIC VALUE OF CLOUD FORESTS

This chapter describes the theoretical basis upon which this research project was developed. It reviews literature in the fields of cloud forest hydrology and conservation and resource economics, specifically valuation of protected areas.

2.1 DEFINITION AND DISTRIBUTION OF CLOUD FOREST

The term "cloud forest" is not a scientific term and does not correspond to one specific forest ecosystem. Rather, it represents a combination of climatic and vegetative factors. A working definition developed by an interdisciplinary group of scientists and conservation professionals was provided by Hamilton et. al. (1993):

> The tropical montane cloud forest is composed of forest ecosystems of distinctive floristic and structural form. It typically occurs as a relatively narrow altitudinal zone where the atmospheric environment is characterized by persistent, frequent, or seasonal cloud cover at the vegetative level. Enveloping clouds or wind-driven clouds influence the atmospheric interaction through reduced solar radiation and vapor deficit, canopy wetting, and general suppression of evapotranspiration. The net precipitation (throughfall) in such forests is significantly enhanced (beyond rainfall contribution) through direct canopy interception of cloud water (horizontal precipitation or cloud stripping) and low water use by the vegetation.

The geographic distribution of cloud forests is determined by geographic and climatic factors, such as topography, the direction and velocity of predominant winds, average humidity, and processes affecting cloud formation and orographic rainfall, or rainfall caused by the elevation of air over mountain barriers. The adiabatic rise of humid air causes condensation at a certain level, which produces clouds.

Because of regional and local variations in climate, it is not possible to establish rigid altitudinal limits for the distribution of cloud forests. Although the term used by Hamilton et. al. is tropical *montane* cloud forest, the word montane in this context does not correspond to Holdridge's (1967) life zone classification system, and although the belt of dense clouds in the humid tropics is generally found between 1200 and 2500 m., several studies cited in Stadtmüller's 1987 revision of cloud forest literature have described cloud forests above 3000 m. or below 1000 m.. According to the Holdridge life zone system, cloud forests are found predominantly but not exclusively in premontane and lower montane moist, wet and rain forests (Stadtmüller, 1987).

Among the outstanding biotic factors that characterize cloud forests is the abundance of epiphytes, due to the constant humidity of these ecosystems. Bromeliads, orchids, and other epiphytes, as well as mosses, capture nutrients by taking advantage of the leaching that accompanies fog drip. In elfin cloud forests, in which low temperatures, winds and scarcity of nutrients stunt vegetation height, epiphytes and mosses can even cover the soil surface, which always consists of a thick layer of organic matter.

Endemism of flora and fauna is particularly pronounced in cloud forests, especially when cloud forests are found in close proximity to relatively dry zones (ibid.). Endemic species have often been an important factor in achieving the protection of these areas, and Vasquez-Garcia (1993) discusses the importance of developing special strategies for the protection of cloud forests that consider "the uniqueness and discontinuity of these island-like ecosystems."

According to Nuñez (1996), research conducted by Landesbund Sur-Vogelschutz in 1990 estimated cloud forest cover in Guatemala to be 1,900 km^2, of which 600 km^2 is located in the Sierra de las Minas. The rest is located in the Cuchumatanes, Chama, Yalijux and Chuacus mountains, northwest of the Sierra, as well as in the southwestern volcanic range. Most of these cloud forests have been given formal protection, under the Protected Areas Law.

In Honduras, 31 montane reserves containing cloud forest have been legally declared and encompass a total of at least 4,092.6 km2 of cloud forest, which represents 3.6% of the national territory of Honduras (Mejía and Hawkins 1993). In addition to Cusuco National Park, the Honduran reserves containing cloud forest include Celaque, La Muralla, La Tigra, Pico Bonito, and Santa Bárbara National Parks. However, it should be noted that in neither country is this legal protection sufficient to protect these forests, unless it is accompanied by adequate management activities.

2.2 HYDROLOGIC CHARACTERISTICS OF CLOUD FORESTS

Three hydrologic characteristics of cloud forests make them very significant for the maintenance of water quantity and the temporal regulation of flow. First, by serving as living barriers in the aerial circulation of clouds, the trees and other vegetation in cloud forests capture mist, or what is called "horizontal precipitation," which has been shown to add significant quantities of water to the hydrologic cycle that is not measured by standard rain gauges. Second, because frequent cloud cover causes low evapotranspiration, cloud forests have among the highest streamflow:precipitation ratio of any forest type (Bruijnzeel 1990). Third, cloud forests are believed to play a significant role in supplying water to downstream areas during rainless periods (Stadtmüller and Agudelo 1990; Zadroga 1981; Hamilton with King 1983).

2.2.1 Horizontal Precipitation

Two methodologies are broadly accepted for the quantification of horizontal precipitation: (1) the use of "fog catchers," and (2) the comparison of throughfall (canopy drip) under a forest stand with rainfall in an open area. Fog catchers utilize artificial obstacles such as wire screen or cloth to capture tiny droplets of fog and are described more thoroughly in Baynton (1969), Cavalier and Goldstein (1989), Ved (1973), and Vogelman et al. (1968). The second approach is considered more accurate, because horizontal precipitation depends in part on the structural characteristics of the vegetation, which are unique to each forest canopy; thus it is difficult to extrapolate from artificial surfaces (Stadtmüller 1986; Bruijnzeel and Proctor 1993). However, the results obtained through the second approach can be quite site-specific and not representative of the total ecosystem (Stadtmüller 1986).

The second approach relies on the following formula:

$$T = P - I_c - S + I_h$$

where
T = throughfall, or that proportion of total rainfall that reaches the forest floor
P = total precipitation, as measured in an open area or above the forest canopy
I_c = canopy interception, rainfall that is retained by the forest canopy and later evaporated
S = stemflow, rainfall that is intercepted by the vegetation and flows down the tree trunks
I_h = horizontal interception, or the condensation of fog droplets on the vegetation

Not all precipitation reaches the forest soil to supply plants or generate streamflow. A part is captured by the vegetation and is generally considered a loss because it is evaporated back to the atmosphere. However, in cloud forests, interception includes two components: a loss of water due to evaporation of canopy interception and a gain of water due to the capture of fog drip. In non-cloud forests, throughfall will always be lower than total precipitation, due to canopy interception. However, in cloud forests, horizontal precipitation can reduce or eliminate the loss due to canopy interception, causing throughfall to be higher than total precipitation.

Because fog drip must be greater than canopy interception in order to show a net gain in the above equation, the second methodology leads to lower estimates of horizontal precipitation. However, if the goal of the research is to determine the gain to net precipitation from fog drip, and to predict how net precipitation would change if the forest were cut, then this approach is more accurate.

A thorough analysis should include the quantification of stemflow, but it is often excluded, because several studies have indicated that it represents less than 1% of total precipitation (Caceres 1981; Rothacher 1963; Steinhardt 1978). However, it has been shown to be higher in elfin forests with high tree density, particularly those that are wind-exposed (Weaver 1972).

A review of the literature on horizontal precipitation indicates that the quantity and relative contribution of fog drip to total precipitation both vary greatly between sites. However, some generalizations can be made. Fog drip is often inversely related to precipitation and is higher during the dry season than during the rainy season, increases with altitude and exposure, and is influenced by local topography.

On the Caribbean coast of Venezuela and Colombia, Cavelier and Goldstein (1989) found that fog interception increased from east to west, whereas mean annual precipitation decreased. Using fog catchers, they estimated that fog drip of 796 mm. occurred on the westernmost site, with precipitation of 853 mm., while at the easternmost site fog drip of 480 mm. occurred with total precipitation of 4461 mm..

Several researchers have found that in sites where precipitation is highly seasonal, horizontal precipitation can be particularly significant during the dry season. In Honduras, Stadtmüller and Agudelo (1990) found that fog drip was high during five of the six dry months of the 1987-1988 hydrologic year, and that it occurred during 96 of the 117 days when rainfall did not occur. In Costa Rica, Dohrenwend (1979) documented cloud sweep on 46 rainless days that added the equivalent of 98.3 mm. of rainfall to the water cycle.

Local topography appears to have a strong influence on horizontal precipitation, which tends to be higher in windward areas, ridges and convex hills. In Pico del Este, the first mountain of the Luquillo range in Puerto Rico encountered by the trade winds coming from the Atlantic Ocean, Weaver (1972) found that rainfall was greater on the leeward slopes but that total precipitation was greater to the windward, due to fog drip. Stadtmüller and Agudelo (1990) found that throughfall represented 179%, 129% and 94% of rainfall, respectively, on ridge, convex slope and concave slope areas. Kerfoot (1969) notes that the close relationship between fog drip and wind velocity may explain why fog drip is particularly a hill-crest phenomenon.

2.2.2 Influence of Cloud Forests on Streamflow

Because many cloud forests are valued as water production areas, it is necessary to examine the effect of forest cover not only on total precipitation but more specifically on streamflow. The following formula, adapted from Dunne and Leopold (1978), is useful to explain the influence of land use on streamflow:

$$S = P - I - ET$$

where
S = streamflow
P = total precipitation
I = interception
ET = evapotranspiration

The formula states that streamflow represents that portion of precipitation that is left over after losses due to interception and evapotranspiration. This simplified formula assumes that the drainage basin is underlain by impervious rock, such that there are no losses or gains in groundwater to or from other basins. It also must be applied on an annual basis, in order to be able to assume no net change in soil moisture or groundwater storage. Otherwise, the formula would be:

$$S = P - I - ET + \Delta SM + \Delta GWS + GWR$$

where
ΔSM = change in soil moisture
ΔGWS = change in groundwater storage
GWR = groundwater runoff

In discussing streamflow, it is important to distinguish between *water yield* (total annual streamflow) and the seasonal distribution of flow, or *flow regime*. When expressing water yield as a percentage of total rainfall, Bruijnzeel (1990) reported that tropical montane cloud forests have among the highest values of any tropical forest. This can be explained by evapotranspiration, which his review of the literature showed to be considerably lower in cloud forests than in other montane forests, due to low radiation inputs and high humidity. While evapotranspiration values averaged 1225 mm/yr. in several lower montane forests, it was estimated to represent approximately 570-775 mm/yr. in cloud forests, taking into account the horizontal precipitation that is re-evaporated as part of ET.

In addition, cloud forests are believed to help maintain dry season flow. This is because horizontal precipitation often occurs during the dry season, when moisture-laden winds are strong but precipitation is low, and also because low decomposition causes high infiltration that contributes to the maintenance of springs and dry-season baseflow.

2.3 HYDROLOGIC EFFECTS OF FOREST CONVERSION

Although several studies have been done to quantify horizontal precipitation, almost no research has been conducted that specifically addresses the effect of deforestation or partial harvesting of cloud forests on either water yield or flow regime. The response of non-cloud forests to conversion and the potentially different response of cloud forests will be discussed.

It is commonly believed that most forests act as giant sponges, soaking up water during rainy periods and releasing it gradually during dry periods, and that deforestation both reduces water yield and destabilizes the flow regime. Although forest soils do generally have higher infiltration and storage capacities than agricultural soils, or soils with less organic matter, forests also use a high level of water, through evapotranspiration and interception. Therefore, when Bosch and Hewlett (1982) reviewed the results of 96 paired basin experiments throughout the world, to determine the effects of forest removal on water yield, they concluded that "no experiments in deliberately reducing vegetation cover caused reductions in water yield, nor have any deliberate increases in cover caused increases in yield." This can be explained by the reductions in evapotranspiration and interception that occur after forest conversion.

To explain further, forest soils have been shown to have higher infiltration rates than soils under agriculture or pasture. Wood (1977) compared infiltration on adjacent areas with the same soil series but different land uses, one of which was always an ungrazed forest. On 14 of a total of 15 sites, he found that the infiltration rate was higher under forest cover than agricultural uses or pasture; for most of the forest sites, the infiltration rate was 5-20 times higher. The forested soils were hydrologically superior, due to their higher porosity, larger soil aggregates and lower bulk density. Numerous studies reviewed by González (1992) agree that forest soils commonly have many properties that contribute to higher infiltration, including: the presence of forest litter that absorbs several times its own weight in water and breaks the impact of raindrops, higher organic matter content, macropores formed by roots, insects, and worms, good aeration, high microbial activity and appropriate soil structure and texture.

However, infiltration is only one of many factors affecting changes in water yield and regulation of flow following deforestation. Streamflow is composed of quickflow following rain events and slower groundwater runoff. A decrease in infiltration and soil moisture storage capacity will contribute to an increase in quickflow and a decrease in groundwater runoff. However, other factors in the following formula will also change that can cause increases not only in overall water yield but also dry season flow following deforestation.

$$S = S_r + S_b = P - I_c - ET - \Delta SM - \Delta GWS$$

where:

S = streamflow

S_r = storm runoff or quickflow, that reaches the storm within several hours or a day after rainfall

S_b = baseflow or dry-weather flow that has percolated through groundwater and reaches the stream slowly over long periods of time

P = total precipitation

I_c = canopy or vertical interception

ET = evapotranspiration

ΔSM = change in soil moisture

ΔGWS = change in groundwater storage

Deforestation causes a large decrease in evapotranspiration and canopy interception. Combined with a decrease in infiltration that causes quickflow to increase and groundwater flow to decrease, one can see why deforestation has been shown universally to increase water yield (in non-cloud forests), as demonstrated by Bosch and Hewlett's (1982) review of 96 paired basin studies.

However, in many tropical regions, including the Motagua Valley of Guatemala, the seasonal distribution of streamflow is far more important than annual water yield. The effect of deforestation on dry season flow depends on the net effect of changes in ET and infiltration (Bruijnzeel 1990; Hamilton and King 1983). For example, if soil conservation measures are taken, then it is likely that the increase in ET will be greater than the decrease in infiltration, causing an increase in dry season flow following deforestation, as has been shown in many controlled experiments. However, careful removal of forest cover and protection of soils are unlikely in most of the humid tropics, where deforestation sometimes involves the use of heavy machinery in inappropriate areas and is almost always followed by improper agricultural practices or overgrazing. Bruijnzeel (1990) argues that "the commonly observed deterioration in river regimes following tropical forest removal is not so much the result of the clearing itself but rather reflects a lack of good land husbandry during and after the operation," and that this is where our hope for the future lies.

Because cloud forests differ in many hydrologic characteristics from other forest types, it is necessary to consider the effects of deforestation on cloud forests separately. Bosch and Hewlett's literature review of paired basin studies did not include any cloud forests, and although very little research has been conducted to examine the effects of cloud forest conversion on streamflow, it is logical that deforestation could cause a reduction not only in water yield but specifically in dry season flow, due to the loss of horizontal precipitation.

For example, Harr (1980) showed that patch logging of a temperate cloud forest, in the Northwestern U.S., not only failed to cause expected increases in water yield but reduced flow during the dry season, in spite of good harvesting practices. Harr predicts that horizontal precipitation may explain both of these results. In the first case, reduced transpiration after cutting was offset by the loss of fog drip in the cut stands, preventing water yield from increasing. In the second case, it is likely that the loss of fog drip has reduced effective precipitation and thus streamflow during summer low-flow periods. Follow-up research predicted that fog drip may have added 882 mm. of water to total precipitation during a year when precipitation in an open area measured 2160 mm. (Harr 1982).

Dohrenwend (1979) reported for a small basin with paramo vegetation in the Talamanca mountains in Costa Rica that "because of the amount of occult precipitation, the area yields more water as annual runoff than it receives as rain measured in conventional rain gauges." In addition to representing nearly 20 percent of the moisture input at this site, horizontal precipitation is particularly significant during the dry season. On a larger scale, summarizing data from four Atlantic slope and four Pacific slope basins in the Talamanca Mountains in Costa Rica, Zadroga (1981) found that runoff exceeded rainfall by 2% on the Atlantic slopes, while runoff represented only 34.5% of rainfall on the Pacific slopes. The Atlantic slope results are attributed at least partially to the lack of quantification of horizontal precipitation in these northeast-facing basins. Both of these studies strongly suggest that deforestation of cloud forest could not only decrease water yield, but also greatly decrease dry season flow.

2.4 CONSERVATION STATUS OF CLOUD FORESTS

Tropical cloud forests represent one of the world's most threatened ecosystems (Hamilton et. al. 1993). Despite greater international concern for the loss of lowland tropical rain forests, in many countries cloud forests are being cut at a much higher rate. Although no estimates are available for the loss of tropical cloud forests, Doumenge et al. (1993) indicate that annual forest loss in tropical hills and mountains is 1.1 percent, compared with 0.8 percent for all forests of the tropics. LaBastille and Pool (1978) predict that cloud forests in Mesoamerica and the Caribbean "are probably disappearing faster than any other forest ecosystem in the neotropics today" and estimate a rate of loss of 20 hectares per minute. As much as 90 percent of TMCFs in the northern Andes may have been lost already (Hamilton et al. 1993).

Although the words "loss" and "disappear" can be inappropriately used in the context of deforestation of lowland forests capable of regenerating within a few decades, succession of vegetation following disturbance is extremely slow in TMCFs and reduces the viability of ecosystem restoration (Scatena 1993). After 18.5 years of monitoring a site that had been cleared and burned by an airplane crash in Luquillo Experimental Forest in Puerto Rico, Weaver (1990) estimated that recovery of original above-ground biomass could take two centuries!

Tropical forests are commonly threatened by permanent conversion to agricultural land, expansion of pasture, migratory agriculture, and illegal timber extraction. Although no data exists on the conversion of cloud forest to migratory agriculture, many experts agree that this represents the greatest threat to these forests (Mejía and Hawkins 1993). Poverty and population growth drive landless farmers onto steeper and steeper areas, where cloud forest is cut to support the cultivation of subsistence crops such as corn and beans. In the upper Jones watershed, cloud forest has been cut within the past year and used for subsistence agriculture.

The establishment of coffee plantations represents another major cause of cloud forest destruction, and the northern slopes of Cusuco give ample evidence of this. Coffee is a culturally significant crop whose cultivation is often encouraged and supported by national agricultural policies. The forest is cut and native species are replaced by nitrogen-fixing shade trees. Coffee is generally cultivated below 1800 m. (ibid.) but on the northern side of Cusuco the natural range of cloud forest extends as low as 900 m. elevation.

Because of their relative inaccessibility, extensive cattle ranching does not threaten cloud forests as much as other forest ecosystems. Nevertheless, in the dry Motagua Valley, it is common for cattle ranchers to send their cattle to the upper portion of several watersheds, because the pine forest and cloud forest retain their humidity during the dry season. It is highly probable that the long-term public cost to the watershed caused by the compaction and erosion of the fragile, steep soils in these areas far outweighs the short-term benefits to individual cattle ranchers.

Overall, the greatest threat to cloud forests may be the lack of widespread appreciation of their socioeconomic value and the need for far greater action on the local level to ensure their long-term protection.

2.5 VALUATION OF PROTECTED AREAS AND SPECIFICALLY CLOUD FORESTS

2.5.1 Need for Valuation Research

The resource depletion and loss of biodiversity that result from the conversion of tropical forest to agricultural land or pasture have often been justified by developing country governments as unavoidable consequences of the need for development. These governments are faced with rapid growth of a largely uneducated population, foreign debt, and little industrial capacity. However, in recent years, the development model that focuses on growth of per-capita income but ignores the protection of the resource base from which this income is generated has come under close scrutiny and is gradually being replaced by more progressive strategies for sustainable development.

Since the mid-1970s, most of the new protected areas established throughout the world have been located in developing countries. Initially interested in protecting scenic areas and recreational resources, these countries now see numerous justifications for setting aside special areas, including the protection of significant ecosystems, biodiversity conservation, watershed protection, wildlife management and others. In 1985, the IUCN's list of protected areas included about 186 million hectares in 100 developing countries (Dixon and Sherman 1990). Although much progress is being made in the establishment of protected areas, many reserves are justifiably called "paper parks" because adequate funds have not been allocated to ensure their management and true protection.

The true value of protected areas is often underappreciated, because many of the benefits they provide are intangible and difficult to quantify, while their costs are quite tangible and often high. Establishment of a protected area involves direct costs (including the immediate purchase price of the land and ongoing management costs), indirect costs (such as damages caused by wildlife to nearby communities), and opportunity costs, or the benefits that individuals or society give up by not being able to use the land for certain productive activities or exploit specific resources (ibid.). At the same time, most of the benefits of the protected area, such as biodiversity conservation, protection of aesthetic resources and culturally significant areas, and watershed protection, provide few or no financial returns for the country.

Although many reserves provide nonmarket goods and services as well as commodities, only the commodities are given a value (price) by markets. For example, timber has a market price, but soil conservation and wildlife habitat do not. Because the public does not have adequate information about the value of many environmental services, resources are depleted for short-term profits, at the expense of future generations. The recent development of a market for carbon offset credits, through joint implementation projects, is an attempt to correct one example of this market failure and use market forces to reduce global warming.

Even when examining only market goods, governments' understanding of the true value of forest products can be inadequate, and this can lead to the degradation or loss of valuable resources. Peters, Gentry and Mendelsohn (1989) conducted an economic analysis of the value of non-timber forest products in Mishán, Peru, to demonstrate that traditional forest uses are more valuable than conversion to forest plantations or cattle ranching.

In the case of protected areas, the unequal distribution of benefits and costs can also contribute to resource degradation. Many of the benefits of protected areas are provided to the public in general, while many of the opportunity costs and indirect costs are incurred by surrounding communities, who are no longer allowed to exploit valuable resources. For example, conserving biodiversity benefits society in general, by protecting genetic resources that could have medical or agricultural value in the future, but this may require closing traditional hunting grounds or prohibiting the expansion of agricultural areas used by poor, landless farmers. Research conducted in Madagascar estimated the average annual opportunity cost associated with the establishment of the Mantadia National Park to be $90 to $190 per household (in 1991 dollars) in the villages located within 7 kilometers of the park (Kramer et. al. 1994). Considering that the average annual per-capita income in Madagascar was $190 in 1988, and that these subsistence farming households produce only $128 worth of rice per year, the cost of lost access to valuable forest resources is particularly high for these households. If these costs are not compensated by society, the probability of poaching, illegal resource extraction and conflict with these communities is very high.

2.5.2 Valuation Principles and Methodologies

Recent developments in valuation research facilitate ecological-economic analysis of the market and non-market goods that protected areas provide. This basic formula (Pearce 1993) is applicable to the valuation of all environmental goods:

$$TEV = UV + NUV = (DUV + IUV + OV) + (XV + BV)$$

where
TEV = the total value of the good expressed in monetary terms
UV = use value
NUV = non-use value
DUV = direct-use value
IUV = indirect-use value
OV = option value
XV = existence value
BV = bequest value

The use value can then be broken down into:

$$VU = VP + VDC + VNCU$$

where
VP = the conventional market (production) price of the good
VDC = the value of direct consumption outside of a market, such as the value of the use of medicinal plants within communities
VNCU = the value of non-consumptive use, such as recreation or education

Indirect use values include the following components:

$$VI = VIS + VO + VE$$

where
VIS = the indirect value of ecosystem services (i.e., nutrient cycling, oxygen production, water supply, etc.)
VO = option value, or the value of using the good in the future
VE = existence value, or the intrinsic value of the good, apart from any potential use

As one can see, valuation includes elements that transcend the mere economic utility of a good based on its consumption, such as services the good provides to society in the present and the future, as well as its intrinsic value as a component of an ecosystem.

The application of valuation theory generates numerous methodological complications, and considering time and resource limitations, it is not always possible to measure all of the value components of a resource or protected area. Nevertheless, it is important to take into account and at least mention the existence of all components, so as not to fall into the fundamental problem of neoclassical economic accounting – the undervaluation of nature (Solórzano et al. 1990).

Also, a complete valuation of the net benefits generated by conservation practices should be accompanied by a quantification of the costs involved in these practices. Thus, within the strict context of cost-benefit analysis, the net benefits of conservation practices should be compared with the net benefits of the elimination of conservation practices, or development of the area or environmental good in question (Pearce 1993). In this way, a comprehensive economic justification of the conservation of a reserve is obtained if:

$$\Sigma(B_t - C_t) \times (1+r)^{-1} > 0$$

where:
B = the value of the benefits of conservation during time t
C = the value of the costs of conservation and management of the reserve during time t
r = the discount rate, according to the economic and financial indicators in effect during time t

Common methodologies used in the valuation of natural areas can be organized into four general categories: techniques based on market prices, cost-based approaches, techniques based on surrogate market prices, and survey-based approaches (Dixon and Sherman 1990). Market prices can be used to determine the value of many environmental services, based on changes in quantity and/or quality of goods traded in the market. For example, the value of a forest for watershed protection can be determined through a productivity analysis that compares agricultural productivity with and without forest conservation. Similarly, travel cost techniques quantify the amount of money that tourists spend to visit a natural area, as a reflection of the demand for that recreational resource. Cost-based approaches are similar, but focus on the costs that would be incurred if a natural area were converted to an alternative use, and these costs are determined by market prices.

Surrogate markets can be used when environmental goods and services have close market substitutes. For example, the value of potable water production by the La Tigra National Park in Honduras was quantified recently by calculating the comparable costs of a water treatment facility (Quesada 1995). Similarly, property values can be used to reflect people's willingness to pay for environmental quality, since the value of land with scenic views, good air quality and/or proximity to natural areas will reflect the value of these assets (Hufschmidt et al. 1983).

Surveys can be used when markets and surrogate markets are not available. Various techniques have been developed to determine how much a specific group of people would be willing to pay to protect specific environmental goods and services. Caution must be used in the application of these contingent valuation techniques, and few applications have occurred in developing countries (Kramer, Healy and Mendelsohn 1992).

2.5.3 Applications to Cloud Forests and Watershed Protection

Although arguments for the protection of cloud forests are often made on the basis of the water supply and water quality benefits they provide to rural communities and urban areas, very little valuation research has been conducted to quantify the socioeconomic value of these areas. However, fairly extensive valuation research has been conducted within the broader (but related) field of watershed protection, to quantify benefits such as soil conservation, reducing risk of landslides, prevention of downstream siltation of dams and canals, and regulation of streamflow. Mourraille, Porras and Aylward (1995) have compiled an annotated bibliography in Spanish of watershed protection, covering the fields of hydrology, economic valuation and economic incentives. Evaluation of watershed management projects requires an interdisciplinary perspective that combines an analysis of the potential biophysical impacts of land use change with a socioeconomic analysis of the costs and benefits associated with these biophysical changes.

Cost-benefit analysis is the valuation method used most commonly in the evaluation of watershed management projects. To date, most research in this area has focused on the on-site and off-site benefits of soil conservation (or costs of soil erosion and siltation), and not on changes in water yield or timing of streamflow.

Valuation research can help not only to assess the true social, economic and cultural value of resource protection and management projects but also to determine how local cost and compensation issues should be taken into account to promote more sustainable management strategies. Maldistribution of the costs and benefits of resource protection are common within watersheds, where poor (and often landless) farmers struggling to cultivate steep hills cause downstream problems such as siltation, degradation of water quality, flooding or reductions in dry season flow.

Echevarría et al. (1995) have conducted an economic-environmental analysis of land use in the Arenal watershed in Costa Rica, in which current land use is compared with land use capacity. They propose a methodology to quantify the private (on-site) and public (off-site) benefits and costs of current land use and to evaluate the influence of market failures and political and institutional distortions on land use decisions, and they discuss the use of incentives as a mechanism for resolving discrepancies between private and social interests. .

An incentives program has been developed to strengthen cloud forest conservation and improve watershed management in La Tigra National Park in Honduras, which covers 7500 ha., primarily cloud forest, and provides 40% of the potable water for the capital, Tegucigalpa. During the driest part of the year (March-May), the proportion of the city's water drawn from La Tigra rises dramatically, as other sources dry up (Stadtmüller 1986). Most of the officially-declared 14,500-ha. buffer zone surrounding the park is privately owned. In order to strengthen the protection of this watershed and its biological resources, while providing benefits to the local people, the IUCN has developed several pilot rural-development projects such as training farms that introduce sustainable management techniques, while maximizing local control over resources (McNeely 1988).

CHAPTER 3: STUDY AREAS IN GUATEMALA AND HONDURAS

This chapter is intended to provide background information about the two reserves where the research was conducted, for those readers who have not yet been fortunate enough to have the opportunity to get to know them firsthand. It includes information on the location, history, legal status, management, natural features and socioeconomic aspects of the Sierra de las Minas Biosphere Reserve in Guatemala and Cusuco National Park in Honduras. The location of these reserves is shown in Figure 3.1.

3.1 SIERRA DE LAS MINAS BIOSPHERE RESERVE, GUATEMALA

3.1.1 History, Legal Status and Management

The Sierra de las Minas Biosphere Reserve is located in eastern Guatemala, between the Motagua and Polochic Valleys, and covers an area of approximately 236,300 ha., measuring 130 km. in length and 10-20 km. in width. The reserve is the most important protected area in Guatemala for biodiversity conservation, because of the great diversity of ecosystems that it encompasses, extending from 150 to 3015 m. in elevation, and encompassing diverse climatic regimes, in a mountain chain that crosses five Guatemalan Departments (Alta Verapaz, Baja Verapaz, El Progreso, Zacapa and Izabal). It is estimated that the reserve includes 70% of the species found in Guatemala.

The Sierra is also one of the best managed reserves in Guatemala, because Defensores has worked to protect the area since 1988. In 1990, the Guatemalan National Commission for Protected Areas (CONAP) approved the technical study of the proposed SMBR and the Guatemalan Congress legally declared the establishment of the reserve, giving the responsibility for administration of the reserve to Defensores. In 1992, the first 5-year Master Plan for the reserve was approved, which was required by law and defined the general political, organizational and programmatic framework within which Defensores would administer the reserve and the base for later 5-year master plans. (Defensores, no date) It is worth noting that this represented the second master plan approved for any of the protected areas established at that time, and to date only three have been written and approved in total (Nuñez, personal communication).

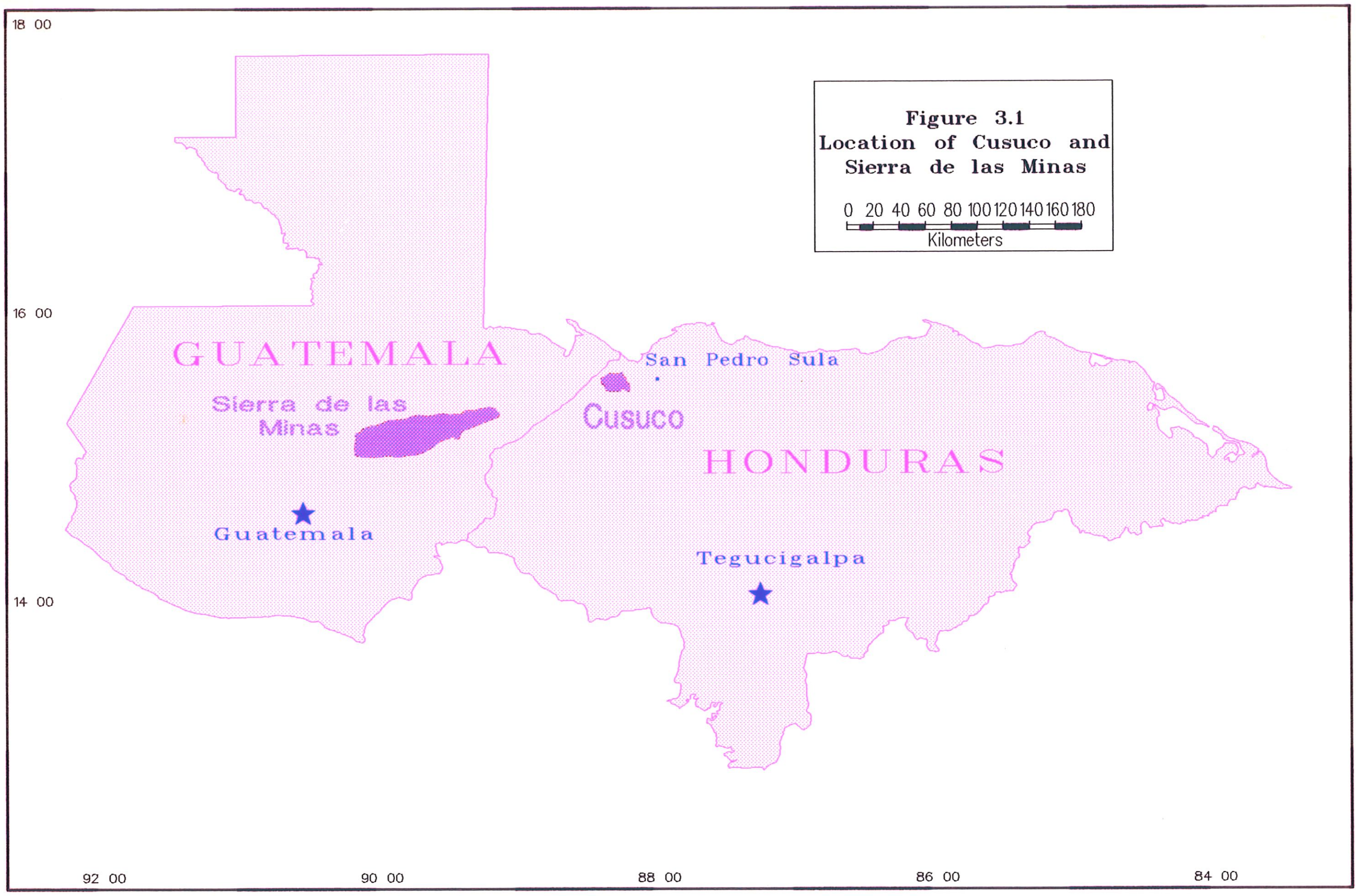


Figure 3.1
Location of Cusuco and
Sierra de las Minas
0 20 40 60 80 100 120 140 160 180
Kilometers
18 00
16 00
14 00
92 00
90 00
88 00
86 00
84 00
GUATEMALA
Sierra de las
Minas
Guatemala
San Pedro Sula
Cusuco
HONDURAS
Tegucigalpa

One of the principal objectives of the reserve, defined by the Master Plan, is the protection of springs and watersheds, due to their socioeconomic value for surrounding communities. The Master Plan proposed 12 directives for management, of which this research is associated with the following four: conservation of soils and water, biodiversity and forest protection, scientific research and monitoring, and environmental education and training.

The reserve is divided into four management zones, including the core zone, the sustainable use zone, the buffer zone and recuperation zone, shown in Figure 3.2. Within the core zone, the principal objectives are environmental preservation, conservation of biological diversity, protection of water production areas, research and ecological tourism. Because most of it is forested, the objective of the sustainable use zone is to promote the utilization of forest resources in an ecologically and socially sustainable manner. Most of the communities are located in the buffer zone, so its principal objective is to promote resource management practices that improve the quality of life of the residents, through environmental education and other activities. The recuperation zone is an area that has been degraded by timber extraction in inappropriate areas and forest degradation; the priority here is forest regeneration for watershed and habitat restoration.

On the administrative level, the reserve is divided into three districts: Chilascó, Motagua and Polochic, each of which is divided into sectors. Three management programs have been developed, within which management activities are conducted. First, the Protection and Management of Wilderness Areas Program encompasses activities related to resource protection, management and research. Second, the Sustainable Development program includes environmental education, ecotourism, forest management, sustainable production, rural extension and human settlements. Third, the Administration program includes organization, finances, training, construction and maintenance of facilities and planning.

3.1.2 Geology and Soils

The SMBR is bordered to the north and south by two depressions, that correspond to the geologic faults of the Motagua and Polochic Rivers. On the northern side it is composed of Paleozoic geologic formations considered the oldest in Central America, and to the east , west and south by anphibolite, marble and serpentine metamorphic rocks.

The geologic history of the Sierra provides evidence of intense change (metamorphism) during the Pre-Permic period, before the advance of the sea at the end of the Carboniferous period, primarily in the north. During the Permic

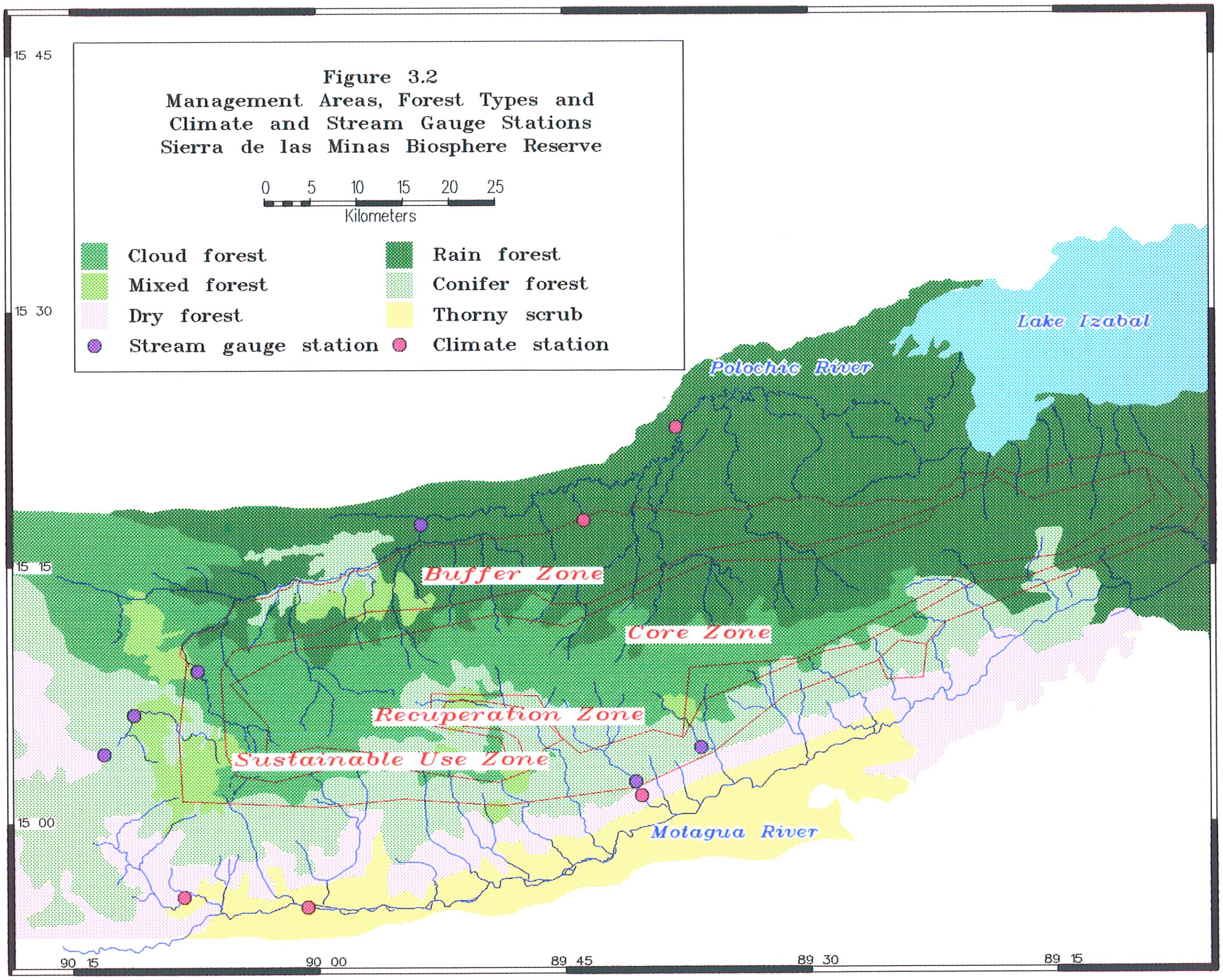


Figure 3.2
Management Areas, Forest Types and
Climate and Stream Gauge Stations
Sierra de las Minas Biosphere Reserve
0 5 10 15 20 25
Kilometers
Cloud forest
Rain forest
Mixed forest
Conifer forest
Dry forest
Thorny scrub
Stream gauge station
Climate station
Lake Izabal
Polochic River
Buffer Zone
Core Zone
Recuperation Zone
Sustainable Use Zone
Motagua River
15 45
15 30
15 15
15 00
90 15
90 00
89 45
89 30
89 15

period, a thick layer of sediments were deposited in this region that were later uplifted and split by mountain-building activity at the end of the Paleozoic period, the Late Cretacic and Eocenic periods.

The soils of the Sierra are the oldest in Central America and range in texture from silt clay to silt, with 0.25-0.5-cm. depth and slopes of 40-80%. Because of this, most of the soils in the Sierra are classified as highly susceptible to erosion and not recommended for agriculture or pasture, only for forest protection and management, with a few small areas that are adequate for agriculture, according to the National Plan for Natural Resources (SEGEPLAN 1975).

3.1.3 Climate and Hydrology

As in most of the tropics, the climate of the Sierra is strongly determined by elevation and the orientation of slopes in relation to principal winds. According to Campbell (1982), "at 1520 m. elevation, nocturnal temperatures regularly range from 15° to 5° C. during the winter and can drop lower, sometimes resulting in frosts between 1300 and 1500 mm." He also found that the relative humidity of the cloud forest fluctuates between 93-95% in the morning, throughout the year, drops to 53-75% at mid-day, and rises again to 91-95% before dusk.

At high elevation, precipitation varies greatly within short distances, and some areas on the Polochic (northern) side receive more than 4000 mm of rain annually. From January through May, the cloud forest generally receives between 50 and 150 mm of precipitation. June is usually the wettest month, with more than 500 mm, monthly precipitation continues at about 400 mm through September, and between October and December it drops to about 250 mm. Precipitation differs greatly between the Polochic and Motagua Valleys, because the high peaks of the Sierra serve as a barrier, causing a rain shadow effect in the Motagua Valley, where annual precipitation can be as low as 500 mm (ibid.).

The Sierra de las Minas is considered Guatemala's greatest producer of water, because out of this mountain range flow 63 permanent rivers, of which 32 flow north, 1 west and 30 south. The Sierra provides water for irrigation, domestic supply, industry, small-scale agroindustry and hydropower generation. Thousands of campesinos (small farmers) and numerous large commercial farms depend on this water to irrigate such basic staples as corn and beans, traditional crops such as coffee and sugar cane, newer (non-traditional) export crops such as melon, tobacco, cardamon, grapes, and vegetables, and cattle pasture.

The water of the Sierra is considered to have high potential for hydroelectric power generation. In the headwaters of several watersheds, pelton-wheel generators are used to provide power for residents, a large commercial dam has been built in the Rio Hondo watershed and several more are being proposed.

Because of the large amount of water produced by the Sierra and its socioeconomic importance, the government manages river gauging stations on six rivers, each of which was established for specific commercial purposes. The location of these stations is included in Figure 3.2. The Pasabien, El Tule and Matucuy stations were established due to interest in developing hydroelectric projects, while the San Jerónimo, Matanzas and Chilascó were established in the San Jerónimo Valley government irrigation district.

At these stations, data are collected twice daily, to estimate daily and monthly river flow. Table 3.1 includes data from these stations and shows that the Matanzas River is clearly the largest, followed by Las Flautas, while the San Jerónimo river is the smallest and has the lowest dry season flow. Inconsistencies in data collection prevented the comparison of data from the same hydrologic year.

Table 3.1 Streamflow Estimates from Gauging Stations Around the Sierra de las Minas

Station Name	River	Year of Data	Annual Average	Maximum flow (m3/s)	Minimum flow (m3/s)
Pasabien	Sunzapote	1984	1.84	3.94	0.55
El Tule	Colorado	1987	1.45	2.60	0.71
San Jerónimo	San Jerónimo	1984	1.84	1.97	0.24
Chilasco	Chilasco	1984	1.01	2.14	0.35
Matanzas	Las Flautas	1974	2.28	5.02	1.14
Matucuy	Matanzas	1976	40.55	82.74	9.39

3.1.4 Ecosystems, Flora and Fauna

The climatic, geologic and physiographic characteristics of the Sierra de las Minas mountain range create great diversity of floral and faunal habitat. The following vegetative associations, based on an adaptation of the Holdridge Life Zone classification system, have been described by Dix (Defensores 1990):

1. Two types of cloud forest:
    - 1.1 Subtropical lower montane rain forest
    - 1.2 Subtropical lower montane wet forest
2. Subtropical lower montane humid forest
3. Subtropical pre-montane wet forest
4. Subtropical premontane dry forest
5. Subtropical thorny scrub forest

Most of the primary forest in the Sierra is cloud forest. The Sierra contains the largest extension of cloud forest in Guatemala -- an estimated 600 km^2. The first type of cloud forest is characterized by annual precipitation exceeding 4000 mm, and this forest is considered the primary habitat of the Quetzal *(Pharomachrus moccino)*. The indicator species for this forest type include *Alpharoa costarricensis* (locally called nogal), *Bruneli* sp. (cedrillo), *Gunnera* sp. (Begonia gigante), and *Magnolia guatemalensis* (magnolia). The second type of cloud forest is characterized by annual precipitation between 1000-4000 mm and is generally found between 1400-2700 m.a.s.l.. Indicator species include *Clethera* sp. (zapotillo), *Pinus maximinoi* (pino), *Persea donnell smithii* (aguacatillo), and *Liquidambar styraciflua*. A few isolated areas within this forest receive less than 1000 mm. of annual precipitation and are referred to as montane wet forest.

Lower montane humid forest is generally found between 1400 and 2200 m. elevation and is identified by the presence of pines (especially *Pinus oocarpa*), oaks (*Quercus* sp.), alder (*Alnus jorulensis*) and the orchid *Encyclia selligera*. Below this, premontane wet forest, found between 700-1400 m. elevation, may be identified by the presence of *Orbigny cohune* (coroso), *Terminalia amazonia* (canxan), *Pinus caribea* (Peten pine) and the fruit tree *Manilkara zapota* (chico zapote).

On the southern side of the Sierra, the premontane dry forest is found between 600-1400 m. elevation, with annual precipitation between 500-1000 mm. Indicator species include the orquid *Encyclia dioica*, *Ceiba aescutofolia*, and *Leucaena guatemalensis* (quiebrahacha). Finally, below 600 m. in the Motagua Valley, the most arid region is characterized by thorny scrub forest, identified by the presence of *Cactus* spp. (locally called cacto, nopal or tuna), *Guaiacum* spp. (guayacan), *Acacia farneciana* (subín o espino blanco) and almond (*Bucida machrostachys*).

The Sierra is believed to provide habitat for at least 885 species of mammals, birds and reptiles and amphibians, including at least 110 species of reptiles and amphibians. Covering enormous ranges in altitude, temperature and precipitation that produce a mixture of neoarctic and neotropical vegetative associations and create an abundance of microhabitats, the Sierra is believed to contain an estimated 70% of all of the species registered in Guatemala, including species of great cultural importance such as the Quetzal (*Pharomachrus moccino*). Cloud forests of the Sierra contain associations of conifers, oaks, and Lauraceae species with an abundance of epiphytes, ferns and mosses, while the middle and lower elevation forests of the Polochic valley contain numerous tropical rain forest species, and the Motagua Valley is characterized by semi-desertic species such as cacti.

Forestry experts consider the Sierra one of the most important conifer seed banks in the world and have registered 17 species that are an invaluable source of germplasm for forestry and agroforestry projects. The peaks of the Sierra also represent evolutionary islands characterized by a high level of endemism that is particularly typical of cloud forests. Documentation of endemic species is currently limited. Droedge (1993) has documented the following three endemic and economically valuable forestry species: *Abies guatemalensis*, *Taxus globossa* and *Prunus guatemalensis*. Research has been conducted to document endemic Coleoptera and orchid species.

The Sierra is also considered one of the last refuges for several endangered species, including the following mammals: jaguar (*Panthera onca*), puma or mountain lion (*Felis concolor*), tapir (*Tapirus bairdii*), white-tailed deer (*Odocoileus virginianus*), mountain goat (*Mazama americana*), wild boar (*Tayassu tajacu* and *T. pecari*), and giant anteater, (*Myrmecophaga tridactyla*). Several of the birds found in the Sierra are also in danger of extinction, such as the horned guan (*Oreophasis dervianus*), the harpy eagle (*Harpya harpyja*) and the migratory golden-cheeked warbler (*Dendroica crysoparea*).

3.1.5 Socioeconomic Characteristics

Approximately 158 communities are found around the Sierra that represent the following three ethnic groups: the Q'eqchi (Maya) are the principal group on the northern side, the Poqonchi (Maya) on the western side and the Ladinos (of at least partial Spanish origin) on the southern side (Defensores 1992). Several clear differences exist between the Mayan and Ladino communities. For example, all of the Ladinos speak Spanish, but 75% of the Mayan population speak only the language of their ethnic group, i.e. Q'eqchi or Poconchi. In these communities, men tend to learn Spanish more commonly than women.

Many of the communities on the northern side of the Sierra are inaccessible by car and lack the infrastructure needed to provide basic social services. Because of this, Ladino communities have a higher literacy rate (58%) than the Mayan communities (25%), and Ladino adults tend, on average, to have a third- or fourth-grade education, whereas Mayans adults have only studied through first or second grade.

Throughout the Sierra, population is growing rapidly, but at a higher rate in Mayan communities, where most couples have five children, than in Ladino communities, where they have an average of three. The most common illnesses include flu, parasites, respiratory diseases and skin infections.

Approximately 35% of the Mayan population is considered economically active, compared to 45% of the Ladino population. Most households earn Q. 200-300 per month (about $33-50), which is very little for households of 5-7 members.

In most of these communities, opportunities for fixed employment are scarce, leading most families to support themselves through a mixture of economic activities. Agriculture represents the base of the economy, and most families cultivate subsistence crops, selling their production of coffee, sugar cane, cardamon or other common crops, or work as laborers for their neighbors or large landowners. Mayan women commonly make baskets, pottery and other crafts to sell within and outside of the communities. Some young men are recruited by the army and some men and women emigrate to the capital or to the United States. In some Ladino communities, including several in the Jones watershed, money sent from family members working in the US represents a very important source of income and has helped reduce pressure on the forest resources of the Sierra (Defensores, 1993, 1994).

3.2 CUSUCO NATIONAL PARK, HONDURAS

3.2.1 History, Legal Status and Management

The System of Protected Areas (SINAP) of Honduras encompasses approximately 105 reserves, and includes several cloud forests that were declared by Law 87-87. Cusuco National Park represents one of these reserves and has received legal protection under several separate laws in the last four decades. In the first half of this century, timber was extracted from Cusuco, until it was declared a protected forest zone in 1959. In 1987, 1100 ha. of Cusuco were declared under Law 87-87, which gave absolute protection to all territory in the nation above 1800 m. elevation. In 1995, the area was expanded to encompass 7,690 ha.

Cusuco is located in northern Honduras, in the Departments of Santa Bárbara and Cortés, within the municipalities of Omoa, San Pedro Sula and Quimistan. The reserve is surrounded by the Cuyamel Valley to the north and the Naco Valley to the south. The park is included in a regional system of protected areas that encompass two water production zones and their buffer zones, shown in Figure 3.3. The area surrounding the park includes 11 towns with about 3,500 inhabitants, concentrated particularly on the eastern side of the park. Access to the park from San Pedro Sula takes approximately 1.5-2 hours on secondary, dirt roads.

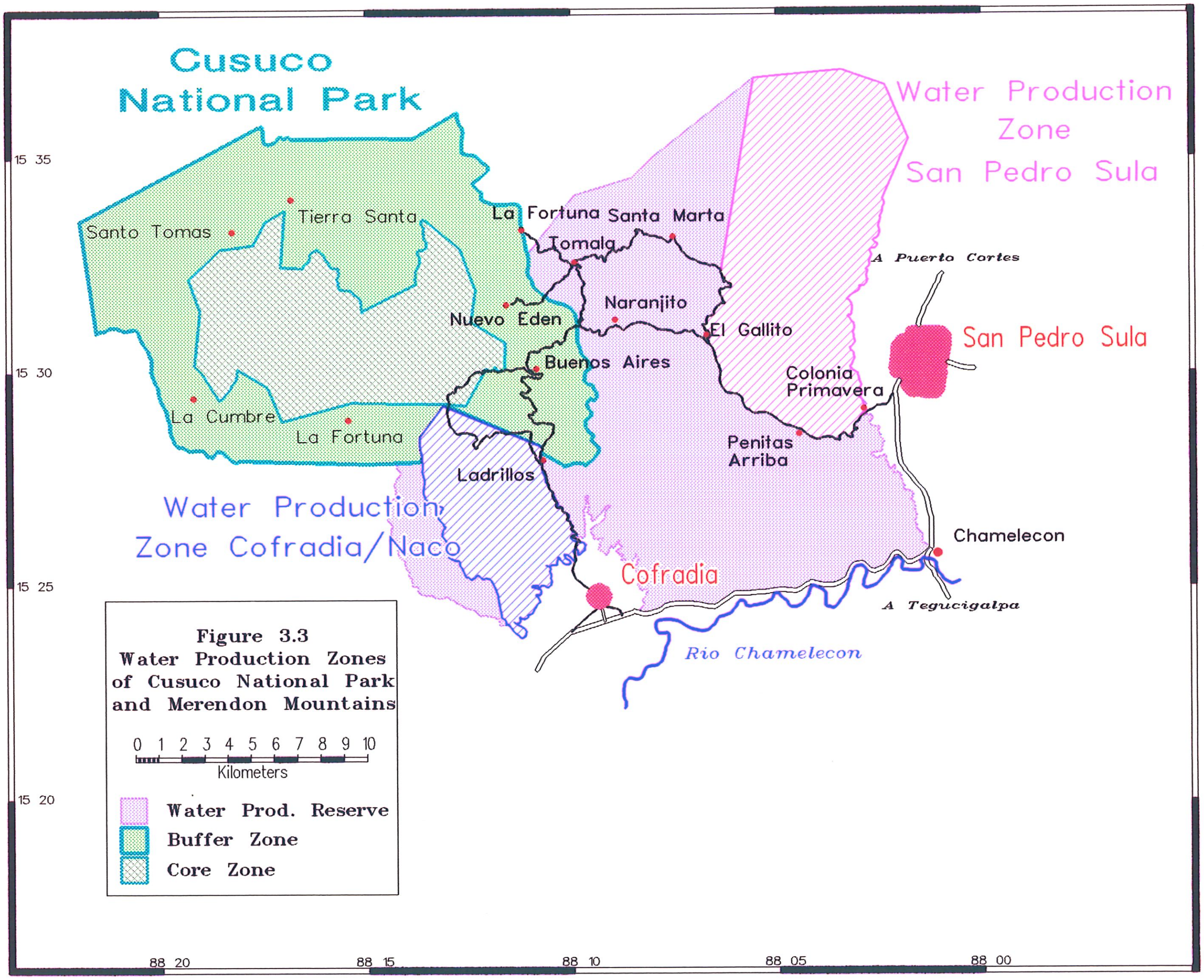


Figure 3.3
Water Production Zones of Cusuco National Park and Merendon Mountains

Until 1995, Cusuco was managed by the Honduran government, through the national forestry agency (AFE-COHDEFOR), but in mid-1995 the AFE-COHDEFOR signed an agreement giving the authority for management of the park to the Fundación Pastor. Since 1992, the Fundación Pastor had been working to mark and expand the core zone of the reserve and develop tourism facilities. A management plan for the park has established six management zones, for absolute protection, regeneration, primitive use, extensive use, intensive use and administration.

3.2.2 Geology

Portillo (1984) describes three geomorphologic regions that compose Honduras, including the Central Northern Plain, the Mountainous Region and the Pacific Coast Region. Cusuco is located in the Merendón mountains, within the Omoa and Espíritu Santo ranges. The park is composed of metamorphic geologic material of Paleozoic origin, including marble, schists, gneiss, quartzite and phylite. In the extreme south and east, intrusive formations from the Terciary and Cretacic periods are found, including primarily coarse-grained granite and diorite (Bioconsult 1994).

3.2.3 Ecosystems, Flora and Fauna

According to a Rapid Ecological Evaluation, the park is composed of two Holdridge life zones, subtropical rain forest at lower elevations and lower montane subtropical forest at higher elevations (Bioconsult 1994). As shown in Table 3.2, the predominant vegetative community is mixed forest dominated by broadleaf species, followed by mixed forest dominated by pine. The area also includes an unusual and interesting dwarf forest.

Table 3.2 Vegetative Communities of Cusuco National Park

Communities	*Area (ha.)*	*Area (%)*
Broadleaf forest	401.8	8
Mixed forest (pine predominant)	2,929.7	12.9
Mixed forest (broadleaf predominant)	19,225.6	84.3
Young Secondary forest	203.2	0.9
Dwarf forest	33	0.1
TOTAL	22,793.3	100

Very little information exists about the flora and fauna of Cusuco. The Rapid Ecological Evaluation estimated that Cusuco has at least 185 genera and 267 species of plants, including 17 species previously undocumented in Honduras. It also reported 29 species of reptiles and amphibians, 46 species of birds and 34 species of mammals. However, a more complete description of the birds of the area, conducted by the Smithsonian Environmental Research Center, reported

200 species. Two new species of Coleoptera have been found in the park, that represent a new genera for the world: *Plusiotis cusuquensis* and *Plusiotis pastori*. In addition, 3 new species of *Chamaedorea* palm have been identified in the park.

3.2.4 Hydrology and Land Use in Each Watershed

Cusuco protects the headwaters of eleven watersheds. The upper portion of most of these watersheds is undisturbed, primary forest, but the cultivation of coffee and subsistence crops, as well as cattle ranching, around the reserve threaten many of these watersheds. Figure 3.4 shows the current land use of the park and buffer zone, according to interpretation of satellite imagery as part of a Rapid Ecological Assessment (Bioconsult 1994). (Because the land use was interpreted before the expansion of the reserve, not all of the new area was included.) One can see that the southern side of the park is characterized by pine forest, whereas the northern, more humid side is characterized by broadleaf forest, which covers a more extensive area. The natural and cultivated pasture indicates the presence of extensive cattle ranching on the northern side of the park, whereas coffee is the principal crop on the southwestern side. Pressure on the park is greatest on the northern side.

The area surrounding the park has experienced strong immigration from other zones of the country in recent decades, which has led to increasing pressure on the forest resources. Deforestation occurs due to slash-and-burn agriculture by landless farmers, the expansion of neighboring properties, and illegal timber harvesting. All of these activities degrade the fragile soils on these steep hillsides, that are particularly vulnerable to erosion due to intensive rains.

Of the 11 watersheds described below, the headwaters of the first 8 are located in the 7,690-ha. core zone of Cusuco, a relatively small zone of high hydrologic importance, composed primarily of cloud forest. Through field work, the limits of the zone of hydrologic recharge were defined, representing the zone of frequent cloud cover. The presence of small, isolated patches of cloud forest below this zone indicate that the zone has moved up in altitude over the past few decades. On the northern side of the park, the recharge zone could have dropped down as low as 600 m., rather than the current location at 900 m., while on the southern side it is likely that the recharge zone was originally located at 1200 m. and is now found at 1400 m..

An analysis was conducted of the current status of each of these watersheds. On the western side of the reserve, the hydrologic recharge zone was located at 900 m.. Most of the Listón, Cortecito and San Carlos watersheds above this altitude

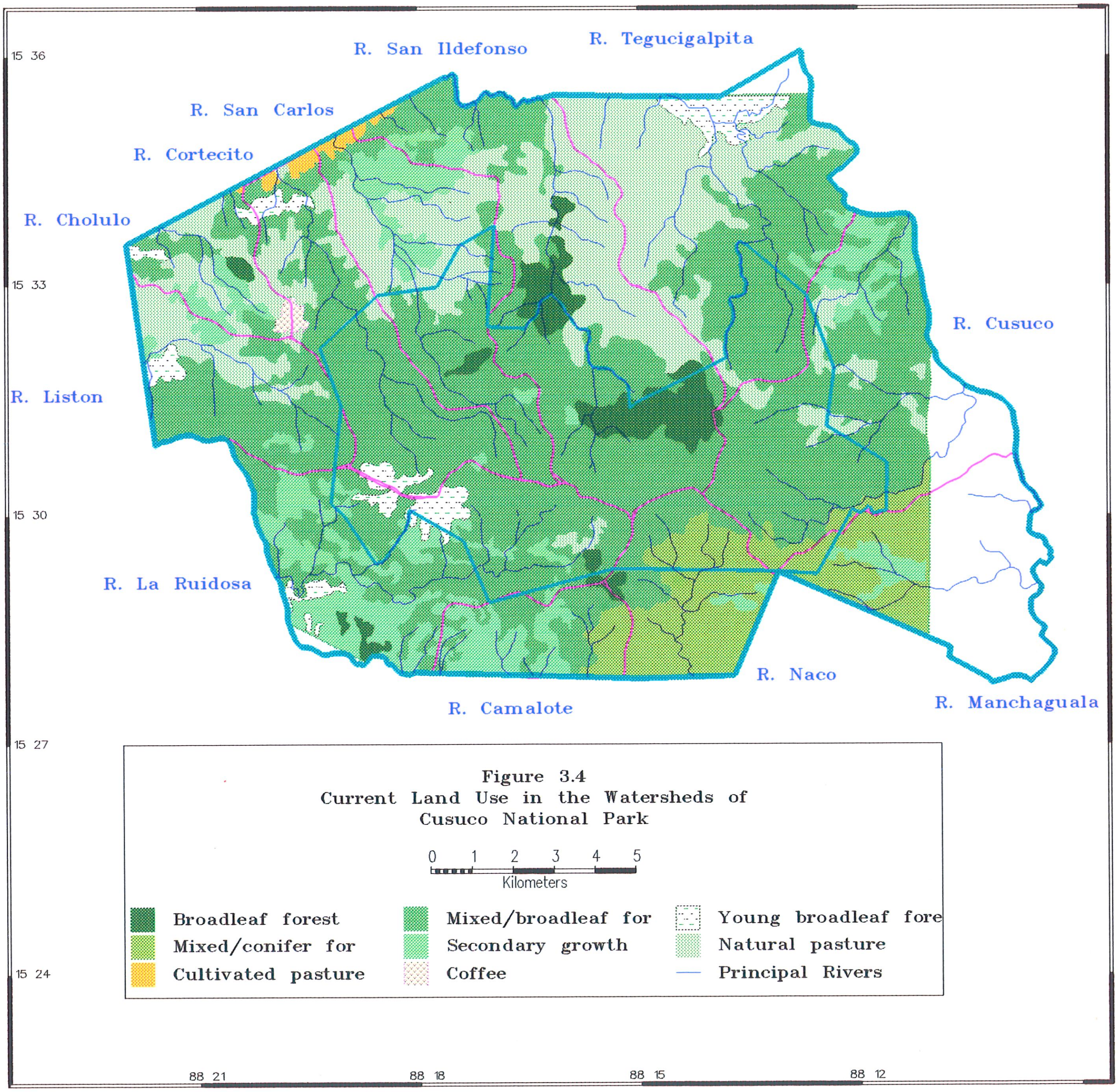


Figure 3.4
Current Land Use in the Watersheds of
Cusuco National Park

are well conserved, covered with broadleaf forest, but some coffee is planted along the border of this zone and some cattle pasture and subsistence agriculture occurs within the cloud forest.

Table 3.3 Watersheds of Cusuco	
Watershed Name	Area (km²)
Listón	14.83
Cortecito	19.89
San Carlos	21.59
San Ildefonso	38.90
Tegucigalpa	33.96
Cusuco	33.28
Naco	13.22
La Ruidosa	30.40
Manchaguala	19.63
Camalote	8.94
Cholulo	8.31

Moving eastward, San Ildefonso and Tegucigalpita are the most deteriorated watersheds in the reserve, due to migratory agriculture, extensive cattle ranching and coffee planted with and without shade trees. Figure 3.4 shows the extensive zone dedicated to pasture, that reaches 1750 m. elevation and covers approximately 40-50% of the recharge zone of these two basins. Deforestation and cattle grazing have caused severe deterioration of the headwaters of the Tegucigalpita basin. The presence of large towns such as Tierra Santa, Nueva Esperanza, and El Corpus, and continuing immigration from the center of Honduras places increasing pressure on the resources of these two watersheds.

On the eastern side of the reserve, the recharge zone starts at about 1200 m. elevation and is fairly intact. The Cusuco watershed contains some agriculture, coffee and pasture that has caused the loss of cloud forest at the edge of this zone, but the Naco and Ruidosa watersheds experience greater pressure from coffee plantations and illegal cutting of pine forest by outsiders as well as community members. The cloud forest should start at 1400 m. in both of these basins, but roads provide relatively easy access, which has contributed to forest fragmentation and watershed deterioration.

3.2.5 Socioeconomic Characteristics

The Merendón mountain range was first colonized in the 1920s, primarily by Salvadoreans. Between 1950 and 1970, immigrants came from the interior of Honduras, especially from Santa Bárbara, Intibuca, Lempira, Ocotepeque and Copán. There are eleven communities around the park, and information available for nine of them indicate a total of 379 households, half of which are located east of the park, 35% to the north and 15% to the southwest.

The most common land use in the Merendón mountain range is coffee cultivation, followed by subsistence agriculture, both of which dominate the landscape on the eastern and southwestern sides of the reserve. The northern side, however, is characterized by extensive cattle grazing, with herds from 3 to 100 cows, as well as some coffee and a bit of subsistence agriculture.

There are several institutions working in and around Cusuco, including community associations, regional and national government agencies, religious organizations, and development agencies developing programs in agriculture, health and education. Several private groups, including FUNHBANCAFE, CARE and IHNESCO, offer sustainable resource management programs, ASOMA develops environmental education programs, and the Fundación Pastor focuses on the protection and management of the park. In addition, in 1994 an Interinstitutional Coordinating Commission (CIM) was formed to coordinate the many activities conducted within the zone of the municipal reserve of San Pedro Sula. The CIM is directed by the Municipal Water Authority (DIMA), which manages this reserve.

CHAPTER 4: MATERIALS AND METHODS

Both biophysical and socioeconomic research were conducted to determine the hydrologic and socioeconomic value of cloud forests. The hydrology research took place in both the Sierra de las Minas Biosphere Reserve and Cusuco National Park. In the Sierra, horizontal precipitation was quantified in the headwaters of the two study watersheds and a pair of basins on the western side of the reserve was used to analyze the effect of land use on runoff. These sites are located in Figure 5.1. In Cusuco, as shown in Figure 5.2, horizontal precipitation was quantified in four areas, including two windward sites and two leeward sites, and a pair of basins was established on the northern side of the park, in Tierra Santa.

Socioeconomic research was conducted only in Guatemala, because the contrast between the humid cloud forest in the uplands of the Jones and Hato basins and the arid agricultural valley below creates an interesting relationship between water production and demand. Land use was determined through photointerpretation, irrigation was quantified and agricultural productivity was determined through a survey of the farmers. Finally, a model was built to simulate the potential hydrologic and socioeconomic effects of deforestation, by combining the paired basin, water use and agricultural productivity data. The methodologies used to collect all of the hydrologic and socioeconomic data are explained in this chapter, but the structure of the model is explained with the simulation results in Chapter 7.

The Jones and Hato watersheds were chosen for the socioeconomic research because they demonstrate contrasting land use regimes. Pasture dominates the landscape in the middle and lower Jones watershed, while the uplands are forested. Hato has been more intensively settled, with communities and agricultural land reaching into the headwaters of the basin, but annual and perennial agriculture predominate and there is almost no pasture.

4.1 HYDROLOGY RESEARCH

4.1.1 Horizontal Precipitation

Horizontal precipitation was quantified by comparing precipitation in open areas with forest throughfall (precipitation under the cloud forest in adjacent areas). The theory behind this methodology was explained in Chapter 2.

Special gauges were constructed in each country, based on the experience of Stadmüller and Agudelo (1990) in Honduras. Each gauge consisted of a 52-cm funnel made of aluminum sheeting, given rust-protection sealing and painted, with a base constructed of 1/2" steel pipe, attached to a plastic tube that drained into a covered plastic container. In the Hato watershed in Guatemala, 2-m. long and 25-cm. wide troughs were also used. The funnels and troughs were nailed to wooden posts and wire screen was placed at the base, to prevent the drainage pipe from becoming clogged by leaves and other debris. The size of the water storage containers varied from one season to another, depending on expected precipitation. Data collected in ml. was later translated to mm. according to the area of the funnel, each of which was measured individually, to account for small differences in size.

Data were collected from January 1995 through April 1996. Four of the six study sites were stratified altitudinally. Initial sampling intensity included at least three throughfall gauges and one open-area gauge located randomly at each altitude in each study site. Preliminary data analysis determined the need to intensify the sampling. So, in July 1995 additional throughfall and open-area gauges were added at each altitude in each site, resulting in a total of four to six throughfall gauges and two or three open-area gauges at each study site.

4.1.1.1 Guatemalan Research

In Guatemala, sampling locations were established at 5 different altitudes in the Jones watershed and at 4 different altitudes in the Hato watershed. In each watershed, the lowest altitudinal site was established at the lower limit of the cloud forest and the highest altitudinal site was defined as the highest site where an open area could be found and it was logistically feasible for the local assistants to collect the data at least twice per month. Data were collected every 4 days from January 1995 through January 1996 and once per week from February through April 1996, except at the highest site in Jones, where difficulty of access required that data be collected once every two weeks..

In the Jones watershed, equipment was installed at 2400, 2200, 2100, 2000, and 1900 m., in the headwaters of the Colorado River basin. All of these sites (located in Figure 6.2) are characterized by broadleaf forest and an E/NE aspect. At the lower three sites, the forest is fragmented but canopy density was found to be high (90-91%). The number of trees per hectare varied from 480 to 820 and basal area from 21.01 to 44.63 m^2/ha. Basal area was highest at 2200 m. (70.82 m^2/ha.). The highest site, at 2400 m., was characterized by a thicker layer of soil organic matter and the largest number of trees (1040 trees/ha.), including many of shorter stature. Canopy density at the top two sites was 82-87%.

In the Hato watershed, open-area gauges were installed at 2750 m., 2550 m., 2200 m. and 1900 m., and throughfall gauges were installed at random locations in the surrounding forest, up to a distance of 100 m. in altitude. The location of these areas is shown in Figure 6.8. In this basin, the higher two sites face W/NW and the lower two S/SE. The top two sites are characterized by mixed and broadleaf forest, respectively, and have a heavier load of epiphytes and lianas than the lower sites, quantified as an average of 1.32 and 0.64, respectively, on a scale of 0 to 3, compared with 0.31 and 0.20, respectively, for the lower two sites. The higher two sites also have a lower proportion of small-diameter trees and more medium- and large-diameter trees. The lower two sites are characterized by mixed forest, with a slightly higher number of trees per hectare and lower basal area (averaging 41.68 m^2 compared to 50.56 m^2/ha. at the higher sites), and canopy density is lower, averaging 84% compared to 94% at the higher sites.

Climate data were collected in each watershed, on the same day that precipitation data was collected. Maximum and minimum temperature, relative humidity, wind direction and wind speed were measured, using simple, portable equipment. These data were collected in open areas at 2000 m. elevation in the Jones watershed and at 2550 m. elevation in the Hato watershed. In the Hato watershed, climate data were also obtained from a government climate station established at the La Trinidad farm, at approximately 1850 m. elevation. Data collected include precipitation, maximum and minimum temperature, temperature in the morning, afternoon and evening, and cloud cover.

Because the early months of the 1995 rainy season produced large quantities of negative interception in the Hato basin, stemflow collars were installed to determine the significance of stemflow in the hydrologic cycle in this forest type. At 2550 and 2200 m., forest parcels were established in which stemflow collars were installed on 8 trees, including 2 in each of 4 diameter classes. Stemflow data, collected in ml., was converted to mm. of precipitation, according to the diameter of the tree and the basal area of the site.

In the Hato watershed, standard rain gauges were also installed near the homes of local residents in the middle and lower portions of the watershed. Daily rainfall from these gauges was compared to rainfall in the upper watershed, to determine altitudinal differences in precipitation in this region.

4.1.1.2 Honduran Research

In Cusuco, horizontal precipitation was measured on the windward side of the park, in Tierra Santa and Jimerito, and on the leeward side of the park, in Jilinco and Cusuco, as shown in Figure 5.2. In Tierra Santa, open-area gauges were placed at 900 m. 1000 m., 1200 m. and 1400 m. elevation, and throughfall gauges were placed in adjacent forest. This area faces the coast and is characterized by broadleaf forest and a medium-to-high level of epiphytes and lianas, ranging from 1.1-1.5 and 1.4-2.7, respectively, on a scale of 0-3. Jimerito is located further from the coast but faces northeast and its steep slopes are open to coastal breezes. It is characterized by both broadleaf and pine forest. Gauges were installed at 1400 and 1600 m..

Cusuco, at the entrance to the park at 1600 m. on the southern side, is a relatively flat, sheltered site on the leeward side. Having been the site of major timber harvesting through the 1950's, it is now characterized by mature pine and mixed forest. Jilinco Mountain (Cerro Jilinco), the highest peak in the park, contains dwarf forest, with many small stems, a heavy load of epiphytes and a thick layer of soil organic matter. Although technically this area is on the leeward side of the park, it is a high ridge open to winds from all directions. Equipment was installed between 1900-2200 m. and data were collected every two weeks.

In Cusuco, at the park visitors' center, the throughfall gauges were initially compared to a standard government rain gauge. However, large disparities were found in the data, either due to the difference in equipment or errors on the part of the government agent responsible for data collection. Therefore, funnel gauges were installed in the open in July 1995, and all data collected before this were not analyzed.

Two climate stations were established in the homes of local residents, at 1600 m. in Cusuco and at 850 m. in Tierra Santa, as shown in Figure 5.2. Precipitation, relative humidity, wind direction, wind speed and cloud cover were measured at each site twice per day.

4.1.1.3 Data Analysis

An analysis of variance (ANOVA) was conducted on all of the horizontal precipitation data from both Guatemala and Honduras, to answer the following questions:

> (1) Is there a significant difference between throughfall and open-area precipitation, either due to horizontal precipitation (causing a net gain under the forest) or due to vertical interception (causing a net loss)?
> (2) What factors, such as altitude, season or site, are correlated with a significant difference between throughfall and open-area precipitation?

Each study site was treated as an individual area, and analyses were performed to determine the significance of the study area, altitude and season on the rate of precipitation per unit of time in forested and deforested areas. The total sample size was 124 rain gauges in 6 study areas (the two watersheds in the Sierra and the four sites in Cusuco). A natural log transformation was done, to resolve heterogeneity of variance. Also, two extreme outliers were removed; including one gauge whose measurements were extremely high and another extremely low during the dry season in the Hato basin.

Separate analyses were conducted for each season. The hydrologic year was divided into 3 seasons: rainy, dry and windy. Although there are some climatic differences between the study sites, the rainy season was defined generally as May through October, the dry season as November and March-April, and the windy season as December-February. The "windy" season is intended to capture that part of the year when cold fronts from the North are active, bringing strong winds and cloud cover. It is a transition period between the rainy and dry seasons.

4.1.2 Effect of Land Use on Streamflow

The accepted methodology used to study the effect of changes in land use on water yield and regulation of streamflow involves the selection of pairs of basins with similar biophysical and topographic features and similar initial land use. Streamflow in the two basins is calibrated statistically over a period of at least two years and then land use is altered in one of the and the hydrologic effect on the experimental basin observed in relation to the control basin (Bruijnzeel 1990). For example, many studies have been conducted on the effect of deforestation on water yield by calibrating two forested basins and then deforesting one of them (Bosch and Hewlett 1982).

Because deforesting a basin was neither feasible nor desirable in these protected areas, this methodology was adapted and pairs of basins were chosen that demonstrate existing contrast in land use. Within each pair, one of the basins had to have at least 70% forest cover and the other less than 30%. The original goal was to establish at least two pairs of basins in each country, but it proved difficult to find pairs with such contrasting land uses within the natural range of cloud forest. In the end, one pair was established in Honduras and another in Guatemala. All of these basins had permanent streamflow.

The first pair was established in Tierra Santa, on the northern side of Cusuco. These are adjacent, small basins, located in the headwaters of one of the small streams that flows into the San Carlos watershed, as shown in Figure 5.2. The deforested basin was 26 hectares and the forested basin 6.5 hectares. The forested basin is characterized by natural forest and a small area (less than one hectare) of shade coffee. The other is completely deforested and used for pasture, coffee without shade trees and residential areas. Wooden weirs were constructed in both streams, to facilitate streamflow measurements. Streamflow was measured daily in the deforested basin and once every four days in the forested basin from July through October 1995 and then daily in both basins from November 1995 through April 1996. Measurements taken in centimeters were converted to liters per second (lps) and lps/km^2. A second pair of weirs established in late 1995 on the eastern side of Cusuco was washed out by a storm only one week after construction, and unusually rainy weather prevented their reconstruction.

In Guatemala, the first basin covers 196 ha., has more than 80% forest cover, and ranges in altitude from 1900 to 2400 m.a.s.l.. It is located in La Alambra, in the town of La Piragua, San Agustin de Acasaguastlan, El Progreso. The second covers 150 ha., ranging from 1400 to 2120 m.a.s.l. and has less than 20% forest cover; dominant land uses include traditional agriculture, fallow land and pasture. It is located in El Jute, near El Jicaro, San Geronimo, Baja Verapaz. The location of both microbasins is shown in Figure 5.1.

In each basin, a trapezoidal (Cipolleti-type) weir was constructed. Stream height was measured twice per day, at 7 a.m. and 6 p.m., and measurements were converted to liters per second (lps). Average daily runoff (in lps) was calculated and, in order to compare runoff from the two basins, this was converted to lps per hectare, based on the size of each basin.

A standard rain gauge was installed in each of the basins and daily precipitation recorded at 7 a.m.. To observe the difference in the hydrologic response of each basin, runoff data was converted to mm./day and hydrographs were made. Although many factors affect the hydrograph, because geology, soils and topography are similar, it is assumed that much of the difference in runoff can be attributed to the difference in land use. This analysis of hydrologic response is considered preliminary, because only dry season data was available.

Data from both pairs of basins were analyzed graphically and, where possible, statistically. Statistical analyses were conducted to test for significant differences in the variance of flow.

4.2 SOCIOECONOMIC RESEARCH ON IRRIGATION IN THE SIERRA

Research conducted to determine the socioeconomic value of irrigation included the following three components: photointerpretation, a comparison of streamflow and irrigation flow, and a survey focusing on land use and agricultural productivity. Each of the two study watersheds in the Sierra was stratified into three zones corresponding to the upper watershed (zone 1), the middle watershed (zone 2), and the lower watershed (zone 3). These zones were defined based on topography, hydrology, climate and principal land uses. Figure 6.2 shows the irrigated portion of each zone; dry land is located on adjacent hills. Zone 1 of Jones includes all land above the union of the Cañas, Colorado, Lima and Blanco Rivers, which occurs at approximately 520 m. elevation; most of the land in this zone is hilly and rocky. Zone 2 extends from 520 m. to 300 m. elevation, where the land is flatter. Zone 3 extends from 300 m. to the union of the Jones and Motagua Rivers, at 150 m. elevation, and includes the flattest land along the floodplain of the Jones River and arid lowland slopes.

As shown in Figure 6.8, in the Hato watershed, zone 1 includes the headwaters of the Hato River, above the union of the Las Nubes stream and the Hato River at 900 m. elevation, where the land is used primarily for coffee, corn, cardamon and dairy pasture. Zone 2 extends from 900 m. to the union of the Hato and Timiluya Rivers at 360 m. elevation, and the principal crops in this area are fruit trees, corn and beans. Zone 3 stretches down to the outflow of the Hato River into the Motagua River at 260 m. elevation, and includes the wide floodplain and adjacent arid lowlands.

4.2.1 Photointerpretation of Current Land Use

Standard photointerpretation techniques were used to determine current land use in each watershed, using false color aerial photos at 1:24000 scale, taken in January 1995. Land use was defined as one of 9 forest types (conifer, broadleaf or mixed, and dense, medium or thin), one of 6 agricultural land uses (irrigated or dry annual or perennial agriculture or pasture), secondary growth (fallow land or early forest regeneration), or communities (residential land use). Land use classification was drawn on transparencies and digitized into a computer mapping program called CAMRIS (Computer-Aided Mapping Resource Inventory System), where rubbersheeting was done, using reference points such as rivers and roads, to correct photographic distortions. The resulting maps are included in Chapter 6.

4.2.2 Comparison of Streamflow and Irrigation

In both the Jones and Hato watersheds, an inventory was conducted of all irrigation channels, noting the altitude at which water was diverted from the river, the local name of the channel, and the number of farmers who irrigate their land with water from that channel. The inventory information is shown in the maps of water diversion (Figures 6.2 and 6.8) and was used to design a flow measurement strategy to relate streamflow and irrigation, to compare water supply and irrigation demand. In each zone of each watershed, streamflow and a group of irrigation channels were measured biweekly during the rainy season and weekly during the dry season. Streamflow was determined by measuring the stream profile and using a velocity meter to determine flow velocity for each section of the stream profile. Irrigation flow was measured along a straight stretch at the beginning of the channel, by measuring the cross-section of the channel and flow velocity.

In the upper and middle portions of the Jones watershed, data were collected from March 1995 through April 1996, to include a complete rainy season and a complete dry season. In the upper basin, irrigation channels 1.1 to 1.9 were measured and the Cañas River was measured at 850 and 540 m., above and below this stretch of channels. In zone 2, channels 4.1 to 4.9 were measured and the Jones River was measured at 480 and 390 m., above and below these channels. In the lower basin, from February through April 1996 (the period of peak water demand), the channels 5.13 to 5.19 and streamflow below 5.19 were measured.

Data were collected in the lower Hato basin from May 1995 through April 1996, and in zone 2 from February through April 1996. In the upper basin, irrigation is done using hoses of 1/2" of 3/4" diameter. Therefore, irrigation flow was estimated by measuring average flow from 3 hoses of each size and using survey data to determine how long the farmers irrigate each month, and the Las Nubes stream was measured at 1150 m. elevation, below most of the irrigation area. In the middle basin, irrigation channels 1.7 to 1.10 were measured and the river was measured at 600 m. elevation. In zone 3, irrigation channels 1.19 to 1.30 were measured and the Hato River was measured at 450 and 290 m. elevation, above and below this section of irrigation channels.

4.2.3 Irrigation Survey

In order to quantify the value of cloud forest for watershed protection, a survey was conducted in both the Jones and Hato watershed, to estimate the value of water used for irrigation, by comparing the productivity of irrigated and dry (rain-fed) land. This productivity analysis uses the market value of agricultural production to quantify the indirect value of an ecosystem service – in this case, watershed protection and maintenance of dry season flow. Because watershed protection represents only one of several environmental services provided by the reserve, a full benefit-cost analysis was not conducted. Had it been possible to quantify all other services, a full analysis could have been done, to obtain an economic justification for conservation or development of the area, as explained in Chapter 2.

Table 4.1 Jones Survey Sample Frame				
Zone	Towns	# Irrigation Channels	# Parcels Irrigated	# (and %) Interviewed
1	El Cajón de Jones: Jones	21	149	23 (15%)
2	Malpaso; Las Delicias Las Pozas; La Palma	12	154	27 (18%)
3	Malpaso: Llano Verde Jesus Maria: Jumuzna Pata Galana	17	118	20 (17%)

Fifteen percent of the farmers in each zone were interviewed, including approximately one-third who own land near the mouth of irrigation channels, one-third in the middle, and one-third near the end of the channels. In the Jones watershed, 70 interviews were conducted, including 23 in zone 1, 27 in zone 2 and 20 in zone 3. The sample frame is described in Table 4.1. In the Hato basin, 89 interviews were conducted, including 6 in zone 1, 43 in zone 2 and 40 in zone 3, in the communities listed in Table 4.2.

Table 4.2 Hato Survey Sample Frame				
Zone	Towns	# Irrigation Channels	# Parcels Irrigated	# (and %) Interviewed
1	Albores: El Carmen: El Baul	65 (hoses)	65	6 (9%)
2	Chanrayo: Puerta de Golpe El Conte	18	216	43 (20%)
3	San Agustin: Vado Ancho Guaytan Abajo: Magdalena	15	161	40 (25%)

Because many of the farmers own several parcels of both irrigated and rain-fed land, each interview focused on determining the productivity of one parcel of irrigated land and one of rain-fed land. The survey was divided into five sections, to cover basic information about the interviewee, general agricultural information, agricultural and agroindustrial productivity of irrigated and dry land, irrigation problems, and environmental perceptions. The survey was pre-tested and revised. Interviews were conducted by trained assistants (including Defensores field staff) working with the principal researchers. The surveys were conducted between June and September 1995, and farmers were asked to provide information about the May 1994 - April 1995 agricultural year, including the May–December rainy season and the January–April dry season.

Land use was divided into four categories: traditional annual crops (corn, beans, and other subsistence crops), non-traditional annual crops grown for export (chile peppers, melons, tomato, carrots and other vegetables), perennial crops (coffee, sugar cane, fruit trees and firewood), and cattle pasture, used for dairy and beef production. For each parcel of land, annual gross and net agricultural earnings were calculated for each crop, based on crop yield, price, and all labor expenses and inputs such as pesticides and fertilizers.

Because cattle represent a long-term investment, annual cattle purchases and sales will not provide an accurate representation of true net earnings for pasture. Therefore, annual net earnings from cattle were calculated by summing dairy earnings and the market value of annual weight gain, using the following formula:

annual net cattle productivity = (market value of weight gain of calves) + (market value of weight gain of cows) + (market value of weight gain of bulls) + (milk earnings) – (labor costs) – (cost of agricultural inputs)

The value of annual weight gain was calculated using the following table, in which the sale value represents an average of the market figures obtained through the survey, and estimates of weight at specific ages were obtained from the University of San Carlos. When a young calf is 9 months old, it is considered a *ternero* and weighs approximately 500 lbs. At the age of a year and 3 months, it is considered a *novillo* and weighs approximately 850 lbs. By the time it is 2-3 years old, it is considered a grown cow or bull. Because a milk cow produces for 10 years (or 7-8 deliveries), from age 2 or 3 to 12.5, an average age of 7.5 was used. A bull can be used for reproduction starting at age 2-3, but when its offspring reach reproductive age it must be sold; in this case an age of 3.75 is used, taking the average of a productive life from 2.5 to 5 years old. Dairy earnings, labor costs and annual agricultural inputs were obtained from the survey.

Table 4.3 Calculations Used to Estimate the Value of Cattle

Category of Animal	Sale Value (Q.)	Age (yrs.)	Weight (Lbs)	Price/ Lb.	Annual Weight Gain (Lbs)	Value of Annual Weight Gain (Q.)
Young Calf (Ternero)	950	0.75	500	1.9	666.67	1,267
Older Calf (Novillo)	1512	1.25	850	1.78	680.00	1,210
Non-lactating Cow	1460	7.5	1200	1.22	160.00	195
Lactating Cow	2450	7.5	1200	2.04	160.00	327
Bull (Toro, 4.5 yrs)	3500	3.75	1500	2.33	400.00	933

The annual net productive value of irrigated and dry-land pasture were calculated according to the amount of time that the cattle spend on irrigated and rain-fed land, as explained in this formula:

Net productivity of irrigated land = (net productivity of all cattle)*(% of time spent on irrigated land)

To quantify annual irrigation of each parcel of land included in the survey, the irrigation flow data were combined with survey information on the number of hours that each parcel is generally irrigated during each month of the year. For land located along one of the irrigation channels that we measured, this calculation was straightforward. For land located along another irrigation channel, the closest measured channel in the same size class (small, medium or large, according to number of users) was used. Flow was multiplied by one of three correction factors, to account for infiltration: 0.7 for parcels located near the beginning of a channel, 0.5 for those in the middle, and 0.3 for parcels near the end.

4.2.4 Data Analysis

Survey results were first analyzed using descriptive statistics, including frequencies and averages. Data gathered in local units were converted to metric units and 1995 quetzales were converted to 1996 U.S. dollars, using a conversion rate of Q. 6.13 per dollar.

Then further statistical analyses were conducted on the combined Jones and Hato data, to compare the two watersheds and to answer the following questions:

1. How does agricultural productivity differ between the zones and watersheds?
2. How is agricultural productivity related to the water productivity per hour of irrigation?
3. What factors determine productivity per area and per hour of irrigation?
4. Are the differences in agricultural productivity between dry and irrigated land statistically significant?
5. How does the quantity of irrigated land affect productivity per area?
6. What value, in terms of productivity, does each additional hour of irrigation per hectare have?

First, benefit-cost and water productivity relationships were calculated for each zone of each watershed. The benefit-cost relationship represents gross agricultural profits divided by all production costs, including materials and labor expenses. Water productivity represents gross agricultural productivity divided by the annual number of hours of irrigation.

Two multiple regression analyses with semi-Cobb-Douglas formulations were conducted to isolate the effects of several variables on water productivity. The natural logarithm of the productive factors were used in order to be able to assume decreasing returns per marginal unit of these factors. Those parcels of land for which all information was not available were eliminated from the analysis, which decreased the sample size from 137 to 127. The structure of the regression analyses were::

(1) Ln(Productivity) = aLnHrs + bLnInput + cLnLabor + dPercent + eAvailable + fAwareness + gCrop + hLnSize + iProperty + jMixprop + kZone + lBasin + mEduc + nPrecipsq + p

and

(2) Ln(WatProd) = bLnInput + cLnLabor + dPercent + eAvailable + fAwareness + gCrop + hLnSize + iProperty + jMixprop + kZone + lBasin + mEduc + nPrecipsq + p

where:

Productivity = gross agricultural profits per hectare per year

WatProd = water productivity, or dollars of gross agricultural profits per hectare per year divided by the number of hours of irrigation per hectare per year

Hours = hours of irrigation per hectare per year, predicted to be positively correlated with (1)

Input = agricultural inputs per hectare per year, predicted to be positively correlated with (1) and (2)

Labor = labor expenses per hectare per year, negative correlations predicted for both (1) and (2), under the assumption that less labor costs mean higher technological development and greater efficiency

Percent = percentage of all of the farmer's land under irrigation, predicted to be positively correlated with both (1) and (2), because greater land area would mean greater productivity and efficiency

Available = a dummy variable representing water availability, in which 1=always available when needed and 2=not always available when needed, predicted to be positively correlated with (1) and negatively with (2), because scarcer water would be used more efficiently

Awareness= a qualitative variable combining several survey questions about perceptions of environmental change and interest in conservation. Lower values indicate higher environmental awareness. A negative correlation is expected for (1) and a positive correlation for (2), because higher environmental awareness could lead the farmer to decrease the intensity of his production and use water more efficiently, to protect the environment.

Crop = a qualitative variable indicating crop type, including fruit trees, perennial crops, annual crops and pasture. Higher numbers indicate policulture, which could decrease profits but would provide soil and water conservation benefits, so a negative correlation is predicted for (1) and a positive correlation predicted for (2).

Size = size of property in hectares. A positive correlation is predicted for (1) and (2), because larger farms tend to be more technologically developed and productive and use resources (including water) more efficiently.

Property = a dummy variable, indicating land ownership (1=property owner, 0=not property owner). Positive correlations are expected for both (1) and (2), because of the productive benefits of land tenure.

Mixprop = dummy variable, indicating land management (1=rented or managed jointly by two or more farmers, 0=used solely by this farmer). Negative correlations are predicted for both (1) and (2), under the assumption that joint management would be less productive and less efficient.

Zone = a qualitative variable indicating location within the watershed (1=upper watershed, 2=middle, 3=lower). Positive correlations are predicted for both (1) and (2), because the lower portion of each watershed has flatter, more fertile land but less water available, requiring more efficient use of that water.

Basin = a dummy variable for watershed (1=Hato, 0=Jones). No predictions made about the direction of correlations.

Educ = a qualitative variable indicating education level, 0 meaning none and 5 being the highest. Positive correlations predicted for both (1) and (2).

Precipsq = squared average annual precipitation in nearby government climate stations (La Palma, near Jones, and San Agustin, in the Hato basin). The squared value is used under the assumption that greater water availability will increase marginal agricultural returns more than proportionately. Positive correlations are predicted for both (1) and (2), due to the scarcity of rainfall in these regions.

The "precipitation" variable was removed from the initial analyses due to 100% multicolinearity with the variable "basin," but included again in later analyses. Also, due to the high probability of multicolinearity, the variable "hours" was removed from the second analysis.

4.3 OTHER SOCIOECONOMIC RESEARCH

Three small surveys were conducted to determine the socioeconomic value of water used for small-scale hydroelectricity generation, industrial use and domestic supply. These uses of water are important, but not as valuable as irrigation. Only in the case of hydroelectricity generation was it possible to calculate an economic value for water use, because of gaps in the other data sets.

4.3.1 Small-Scale Hydroelectricity Survey

A survey was developed to determine the value and benefit of water used for small-scale hydropower generation. All owners of pelton wheel generators in the headwaters of the Hato watershed were interviewed. These generators are used to supply electricity for domestic needs. The amount of electricity generated and used was determined by quantifying the number of light bulbs and domestic appliances powered by each generator, estimating the amount of electricity consumed by each item, and assigning an economic value according to the market price of a kilowatt-hour of electricity, charged by the Guatemalan Electrical Company.

4.3.2 Industrial Water Survey

A survey was designed to determine the quantity and socioeconomic value of water from the Sierra that is used by industrial companies located in the Motagua Valley. The sample frame was defined through an inventory of all of these companies and selection of those believed to use the most water. The managers of these companies were interviewed, to determine annual water consumption, proportion and uses of groundwater and surface flow, problems related to supply and quality of water, and wastewater treatment. Although the main purpose of the survey was to determine the economic value of this water, most of the companies were unwilling to share the financial information needed for these calculations.

4.3.3 Domestic Water Supply Survey

To obtain information about the socioeconomic value of domestic water supply, a survey was conducted of female heads-of-households in the Jones watershed. The survey was developed by Rebeca Haacker, a German geography student who served as a volunteer for Defensores de la Naturaleza for 6 months in 1994-95, with the assistance of the hydrology research team.

The survey was divided into five sections, focusing on personal information, household economy, water supply and use, problems related to water supply, and environmental perceptions. The household economy section was developed to determine the socioeconomic level of the family according to the quality of their home (type of construction materials, type of stove, furniture, appliances, etc.), what the family uses for transportation, and their sources of income. The women was asked to describe their water supply system, the frequency of water shortages and how their lives change when water does not reach their home. Finally, the women were asked their perceptions about water quality, changes in streamflow, the importance of conservation, and specifically the work of Defensores.

A pre-survey was conducted in the towns of Jones and El Cajon de Jones in January 1995, and several questions were modified. The survey was then administered to 143 women in 13 towns in the Jones watershed. This represented approximately 16% of the sample population; according to the 1991 government census, there are 897 households in this region (including the towns of Jones, El Cajon de Jones, La Espinilla, Mal Paso, Las Delicias, Las Pozas, Llano Verde, Llano Largo, Pata Galana, El Peton, Jumuzna, Jesus Maria and La Pepesca). Interviews were conducted by Rebeca Haacker, with the assistance of Carmen Aldana Morales and Griselda Robinson, both government extensionists who live in the watershed. Each interview was preceded by a short explanation of the goals of the study and concluded with an informal conversation; information from these conversations was used in the analysis where possible. An effort was made to conduct the interviews when men were not present, because many women will defer to men, having been taught to believe that their perceptions and opinions are less important than those of men.

CHAPTER 5: CLOUD FOREST HYDROLOGY RESULTS

5.1 HORIZONTAL PRECIPITATION RESULTS

5.1.1 Description of Study Sites

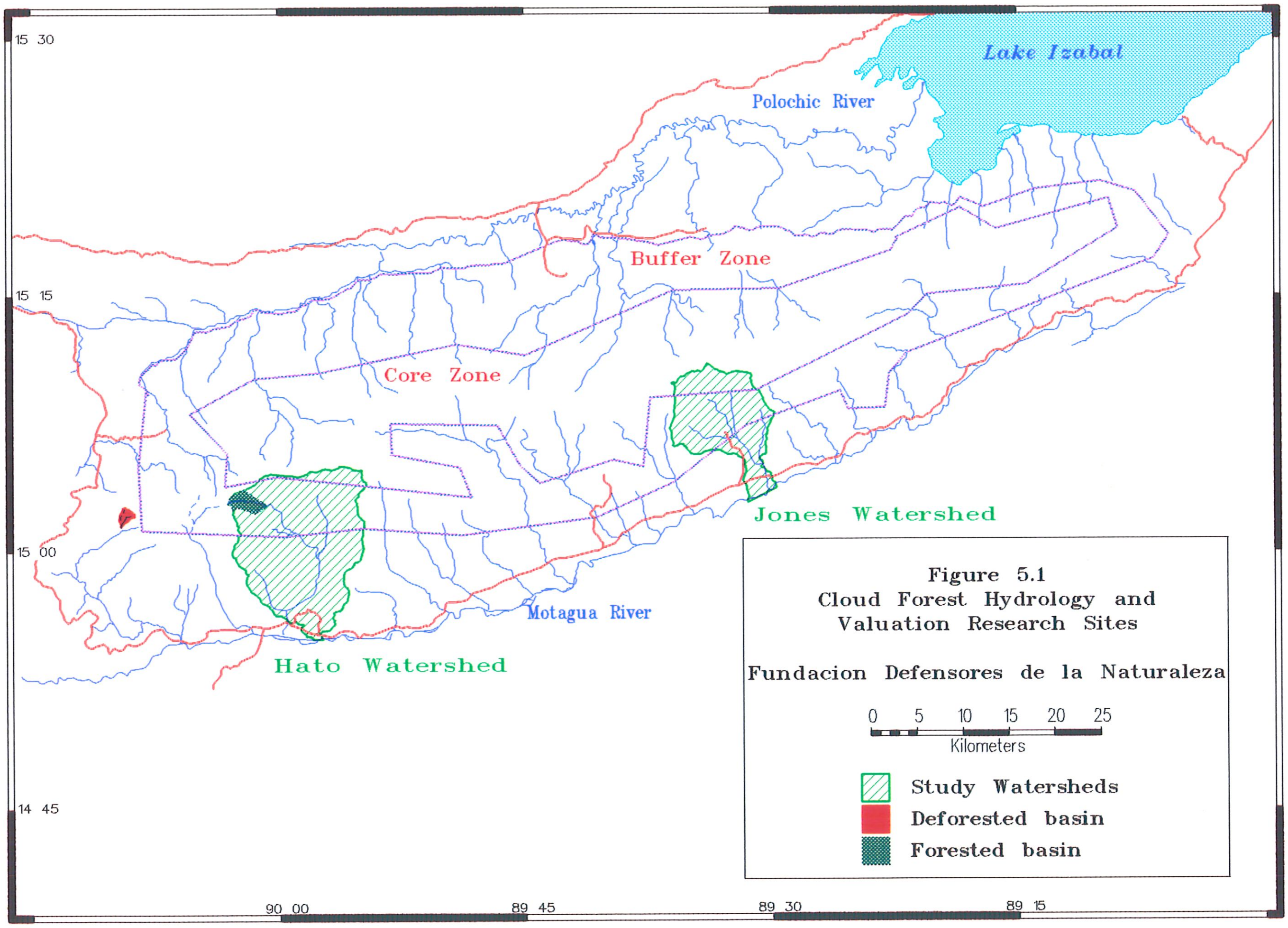
Horizontal precipitation was studied at five altitudes (1900, 2000, 2100, 2200 and 2400 m. elevation) in the Jones watershed and at four altitudes (1900, 2150, 2650 and 2750 m. elevation) in the Hato watershed in the Sierra de las Minas, and in four sites in Cusuco National Park, including two on the windward side of the park and two on the leeward. These sites are shown in Figures 5.1 and 5.2.

For the purposes of analysis, the hydrologic year was divided into 3 categories: dry, rainy and windy. The "windy"season is intended to define that part of the year when cold fronts from the north are active and can cause dense cloud cover and strong winds, which is generally from December through February. The seasonal distribution of precipitation varies between the study areas, because some have more defined dry seasons than others. Nevertheless, the general pattern is for the precipitation rate to be highest in the rainy season, lower in the windy season, and lowest during the rest of the dry season. The one exception during this study period was Tierra Santa, where the precipitation rate was higher during the 1996 windy season than during the rainy season.

In this part of Guatemala, the rainy season generally extends from May through October (although May can be rainy or dry, depending on the year) and the dry season extends from November through April, so the windy

Table 5.1 Comparison of Precipitation (mm)in Two Study Watersheds, Guatemala

Season	Hato Watershed (mm) (at 1900 m.a.s.l.)	Jones Watershed (mm) (at 1900 m.a.s.l.)
Dry 95 (Mar-April)	173	280.12
Rainy 95 (May-Oct)	2,023.47	1,820.52
Dry 95 (Nov)	27.48	106.30
Windy and Dry 95/96 (Dec-Feb)	95.95	364.28
Dry 96 (March-April)	59.65	296.63
Hydrologic Year (May 95 - April 96)	2,206.55	2,587.73


15 30
15 15
15 00
14 45
90 00
89 45
89 30
89 15
Lake Izabal
Polochic River
Buffer Zone
Core Zone
Jones Watershed
Hato Watershed
Motagua River
Figure 5.1
Cloud Forest Hydrology and
Valuation Research Sites
Fundacion Defensores de la Naturaleza
0 5 10 15 20 25
Kilometers
Study Watersheds
Deforested basin
Forested basin

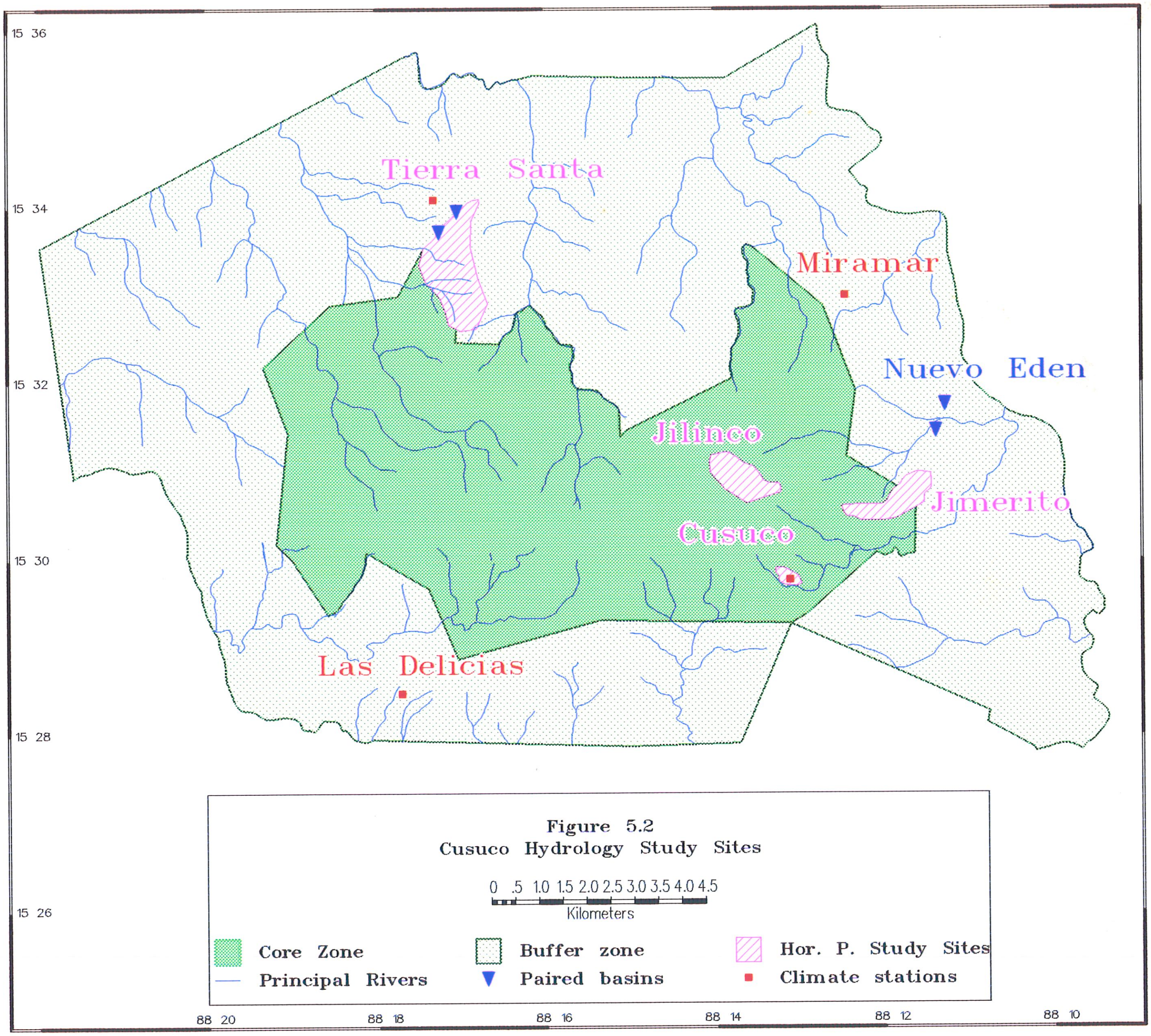


Figure 5.2
Cusuco Hydrology Study Sites

season is a part of the dry season. In general, precipitation is strongest during the rainy season, lower during the windy portion of the dry season and lowest during the non-windy portion of the dry season, which occurs both before and after the windy season. The 1995/96 precipitation data, shown in Table 5.1, generally support this trend, although there appears to be little difference between the windy and dry precipitation rates. Precipitation patterns in the two watersheds are quite similar during the rainy season, but the Hato basin appears to be quite drier during the dry and dry/windy seasons, with precipitation of only 183.08 mm from November 1995 through April 1996, representing less than a quarter of the precipitation registered in Jones during this period.

In northern Honduras, the rainy season extends from June through February and the dry season from March through May, so in this case the windy season is part of the rainy season. The precipitation rate is generally highest in the rainy season (June – November), lower in the windy and rainy season (December – February), and lowest during the dry season (March – May). However, the research period was unusual hydrologically; the early months of 1996 were particularly rainy in Cusuco, and the dry season did not begin until June. As Table 5.2 indicates, although January through May were the driest months of 1995, the early months of 1996 were as wet as the 1995 rainy season. The months of March 1995 through February 1996 were used to calculate annual totals, rather than the standard June-May period, in order to account for the lack of dry season in early 1996.

Table 5.2 Comparison of Precipitation (mm) Between Climate Stations, Honduras

Estación Climática	Tierra Santa	Cusuco
Dry 95 (March-May)	128.10	179.6 mm
Rainy 95 (June-Nov)	3047.55	1695.15 mm
Windy 95/6 (Dec-Feb)	1022.60	641.6 mm
"Dry" 96 (March-May)	1282.50	563.7 mm
Total Hydrologic Year (March 95-Feb 96)	4,198.25	2,516.35

Clearly, the northern (windward) side of Cusuco is far wetter than the southern (leeward) side, especially during the rainy season, when precipitation is 56% higher. However, during the dry season, it may be a bit lower, if the 1995 data are indicative of a typical dry season. The most productive watersheds in Cusuco are found on the northern side, characterized by broadleaf forests, whereas the rivers on the southern side are smaller, with pine forests and mixed forests characteristic of drier areas.

5.1.2 General Horizontal Precipitation Results

The results indicate that horizontal precipitation is a highly seasonal phenomenon. In order to understand the data, it is important to remember that horizontal precipitation was measured as the difference between forest throughfall and open-area precipitation. In the absence of horizontal precipitation, throughfall should be consistently lower than open-area precipitation, because of the loss due to canopy interception, which can be substantial, and the loss to stemflow, which is minimal, according to the literature and results obtained in the Hato watershed. The following formula helps to explain this:

$$T = P - I_c - S + I_h$$

where

T = throughfall, or that proportion of total rainfall that reaches the forest floor

P = total precipitation, as measured in an open area or above the forest canopy

I_c = canopy interception, rainfall that is retained by the forest canopy and later evaporated (considered a net loss)

S = stemflow, rainfall that is intercepted by the vegetation and flows down the tree trunks

I_h = horizontal interception, or the condensation of fog droplets on the vegetation (considered a net gain)

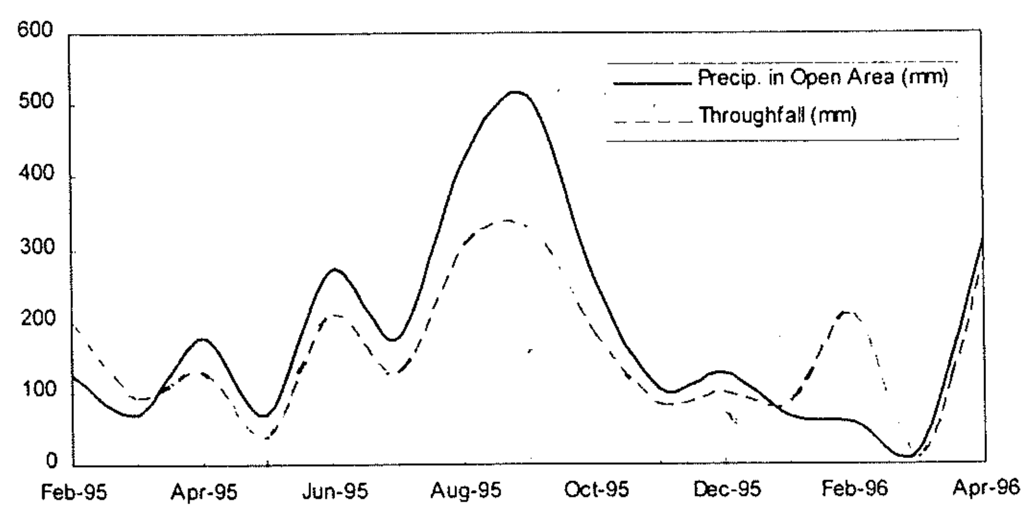
Analyzing all of the study sites together, open-area precipitation was found to be quite significantly higher ($P < .0001$) than throughfall during the rainy season. During this season, it appears that horizontal precipitation is either absent or low enough that it does not significantly reduce canopy interception. However, no significant difference was found between open-area precipitation and throughfall during the dry season ($P=.19$) or during the windy season ($P=.12$), which indicates that horizontal precipitation is present during this time of year and is reducing the loss of water to canopy interception to the point at which throughfall is either roughly equal to open-area precipitation or may be higher for short, but statistically insignificant periods of time.

It is worth mentioning the benefits of canopy (or vertical) interception during rainy periods. While this interception is generally considered a loss, because this water does not reach the roots of plants or contribute to streamflow, Herwitz (1985) notes that "evaporation losses to the atmosphere also mean that there is less liquid water available for the removal of soil particles and dissolved substances in streamflow," which would be particularly important during heavy storms or rainy periods when the soil tends to be saturated and erosion, siltation and even flooding tend to occur. Because many tropical forests experience a much higher frequency of heavy rainfall events than do temperate forests, the role of forest cover in buffering the impact of this rain and reducing its quantity is particularly important.

5.1.3 Guatemalan Results

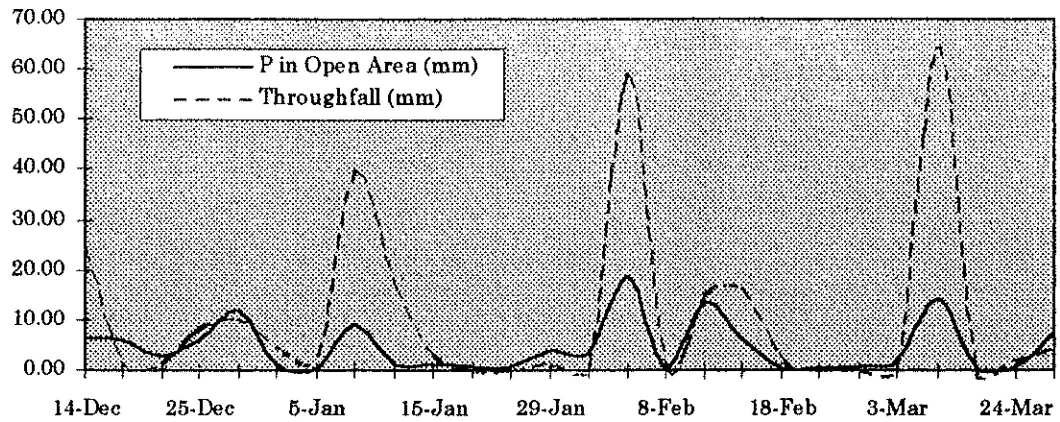
Examining the results from specific sites in Guatemala reinforces the general ANOVA results. As Figure 5.3 indicates, in the Jones watershed at 2200 m. elevation, throughfall was higher than open-area precipitation in February and March 1995 and in January and February 1996, but lower during the rest of the year. Similarly, at the highest site in the Hato watershed, precipitation is much higher in the open areas throughout most of 1995, as Figure 5.4 shows, but from mid-December 1995 through March of 1996 throughfall is almost always higher.

Figure 5.3 Horizontal Precipitation, Jones 2200 m.a.s.l.



An analysis of covariance concluded that altitude is a significant factor (P=.039) in Guatemala, with the highest study sites of all—those at the top of the Hato basin—showing the most significant loss of water to canopy interception during the rainy season. This is probably not due specifically to altitude but rather to the very high level of epiphytes in the forest canopy at this site.

Figure 5.4 Horizontal Precipitation During the 1996 Dry Season, Hato 2750 m.a.s.l.

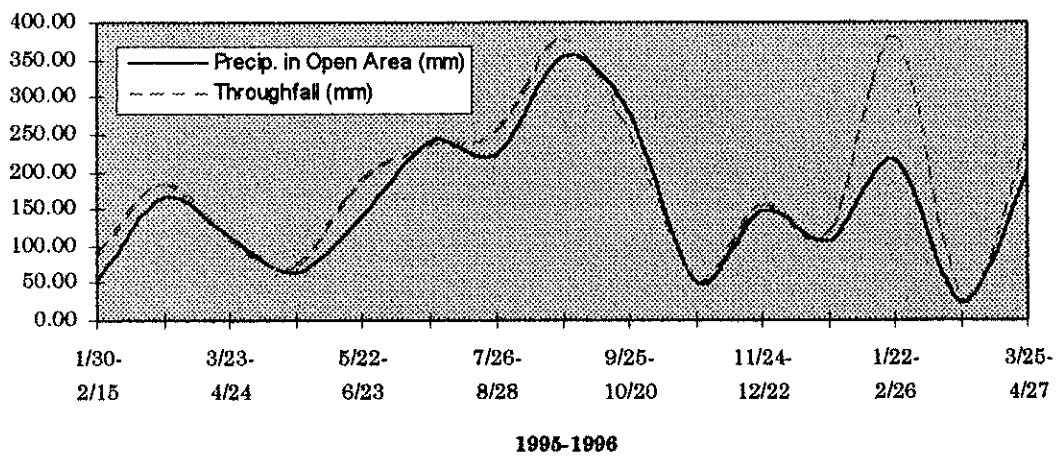


Because of the high level of vertical interception observed at the beginning of the rainy season, stemflow collars were installed at two of the four altitudinal sites in the Hato basin, and data collected from October 1995 through April 1996, to determine if stemflow could be a significant factor in this system, accounting for some of this water loss. In the dense broadleaf forest at 2650 m. elevation, stemflow was found to represent 1.89% +/- 0.017% of open-area precipitation during this period. At 2150 m. elevation, stemflow represented 0.80% +/- 0.89% of standard precipitation. Although stemflow is a part of the hydrologic cycle here, it is clearly only a small component and is justifiably ignored in many studies of horizontal precipitation.

Relative altitude was found to be very important. The highest sites in the Hato and Jones watersheds showed far greater evidence of horizontal precipitation during the windy and dry seasons than did the lower sites. The site that showed the greatest evidence of horizontal precipitation and that did not show horizontal precipitation to be so strictly seasonal was the highest study site in the Jones watershed (at 2400 m.), where throughfall tends to be very close to or slightly higher than open-area precipitation throughout the year, but definitely higher during the two dry seasons and especially higher during the windy portion of the second dry season, from December 1995 through February 1995, as shown in Figure 5.5. Total annual precipitation at this site was 1,963 mm. in the open area and 2,224 mm. under the forest, which represents a net gain of 261 mm or 13%. This translates to an extra 2,610 m^3 of water per hectare, which is clearly a valuable gain for the arid Motagua Valley. Interestingly, at increasing altitude in the Jones study area, annual open-area precipitation decreases from 2521 mm to 1,963 mm, but horizontal precipitation increases.

Unfortunately, this site represented a small percentage of the total study areas, and this altitudinal range represents a very small portion of the watershed, so it had little influence on the overall results.

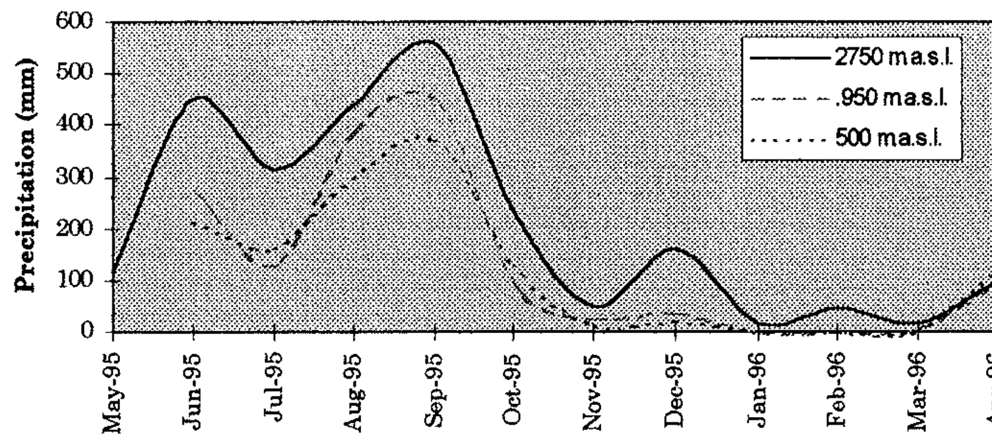
Figure 5.5 Horizontal Precipitation, Jones 2400 m.a.s.l.



However, an ANOVA conducted for only the highest sites of each Guatemalan watershed, examining only the Jan-March 1996 data, indicated that even during this period horizontal precipitation does not increase total precipitation at a statistically significant level. This is because significant variation occurs from one sampling date to the next, as well as between gauges. More intensive sampling is needed at these sites to draw further conclusions.

Although horizontal precipitation was not found to increase total precipitation at a statistically significant level, its influence in offsetting canopy interception and perhaps marginally increasing precipitation should not be undervalued, because it occurs during the dry season, when demand for water is highest – particularly in the arid Motagua Valley. Figure 5.6 shows that while precipitation is almost always significantly higher in the upper portion of the Hato basin than in the arid lower basin, the rain that falls in the mountains during the dry season, from November through April, is particularly important because almost no precipitation falls in the valley during this period. (The data for April are atypical, showing rain during what is usually the driest month of the year.) In the Hato basin, at 2750 m. elevation, average throughfall of 228 mm. exceeded average open-area precipitation of 81 mm. by 147 mm., or 281%, from January through the end of March, the driest portion of this hydrologic year. Water use is very intense during this period, when more water often flows through the irrigation channels than in the river bed, and thus water has its highest socioeconomic value during this time, as will be discussed further in Chapter 6.

Figure 5.6 Comparison of Precipitation in Upper and Middle Hato Basin



5.1.4 Climatic Characteristics of the Hato and Jones Watersheds

Climate data were collected in order to understand the climatic characteristics of the study areas and assist in explaining patterns of horizontal precipitation. It is important to mention that simple, portable equipment was used and that data were collected at the same frequency as the horizontal precipitation data—every 4 days through the end of 1995 and every 8 days during the 1996 dry season—because there are no permanent residents in these cloud forests. However, in the Hato watershed, daily data were also obtained from a government climate station located on the La Trinidad farm (1650 m.a.s.l.), just below the cloud forest research area.

Temperature data highlighted differences between the basins and may help to explain the seasonality of horizontal precipitation, because it appears to occur during the coldest months, when it is likely that low temperatures reduce evapotranspiration. Comparing the two Guatemalan watersheds climatically, the headwaters of the Hato watershed experienced greater extremes in temperature. In Hato, minimum temperatures (experienced between November and March) averaged 13° and dropped as low as -10°C, while during the same time period in Jones they averaged 16°, with an absolute minimum of 0°C. Maximum temperatures, experienced between March and May, reached 39°C. in the Hato basin and 36°C. in Jones. The differences between the basins could be attributed to differences in altitude or topography. The data were collected at

2560 m. elevation in Hato and at 2200 m. in Jones, and the location in Hato was a relatively flat, open area surrounded by tall trees, whereas the Jones site was the top of an open, exposed hillside.

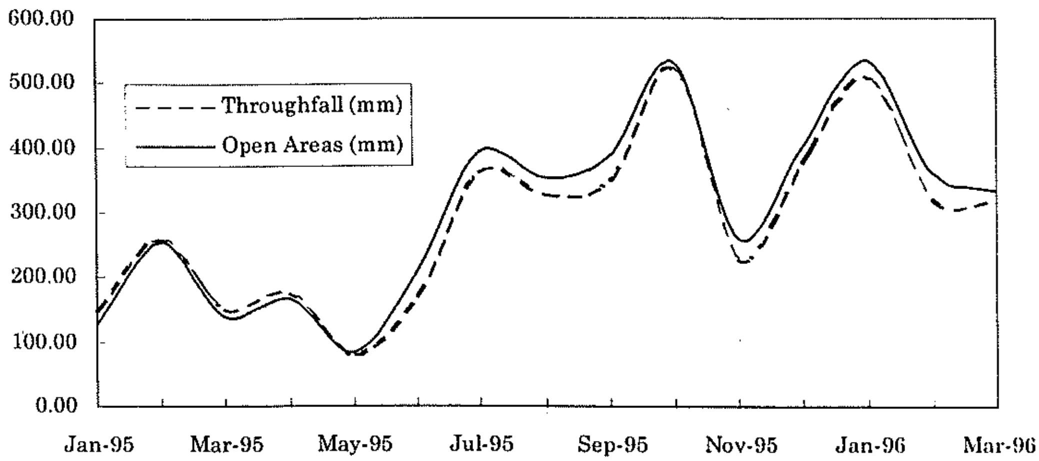
Wind data from Jones could help to explain the occurrence of horizontal precipitation during the windy season. Between December and February, in Jones winds came predominantly from the north, with speeds frequently around 1 meter per second (m/s), with occasional winds above 4.5 m/s, because this site is very open. In comparison, in the Hato watershed during the same period winds came primarily from the south, with velocities between 0 and 1 m/s, probably due to the effect of local topography in sheltering this site. During this period, cold fronts from the north generally bring strong northern winds. For the rest of the year, the wind direction in Jones tend in originate in the east, with low velocities (0 to 1 m/s), while in Hato the direction is varied but velocity also consistently low, from 0 to 1 m/s.

The cloud forest appears to maintain high relative humidity for most of the year. In the Hato watershed, average relative humidity was 85%, with the highest values (95 to 100%) between July and October and the lowest (56 to 70%) between February and March. Cloud cover, measured at 1650 m. elevation (approximately 200 m. below the lower edge of the cloud forest) in the Hato basin, was high. A total of 86 cloudy days and 96 somewhat cloudy days were measured. Clearly, these numbers would have been much higher if it had been possible to take daily data within the cloud forest.

5.1.5 Honduran Horizontal Precipitation Results

In Honduras, horizontal precipitation patterns were analyzed for the period from January 1995 through March 1996. The four horizontal precipitation study sites (shown in Figure 5.2) have the same hydrologic seasons but different intensities of precipitation. Tierra Santa is the rainiest site, with annual precipitation ranging from 3500 to 4000 mm.. Cerro Jilinco was the second wettest site, with annual precipitation of approximately 2750 mm.. Cusuco follows, with annual precipitation averaging 2500 mm.. Finally, Jimerito is the driest site, with annual precipitation of approximately 1750 mm.. These estimates are based on the climate station data from Tierra Santa and Cusuco and the funnel gauges located in open areas in the other two study sites. Because data from April 1995 through March 1996 were used, these may be overestimates, because, as can be seen in Table 5.2, the early months of 1996 were unusually rainy.

Figure 5.7 Precipitation and Throughfall at All Sites, Tierra Santa



Like the Guatemalan data, the Honduran results indicate that horizontal precipitation is a highly seasonal phenomenon and is site-specific. Vertical interception definitely reduces net precipitation during the rainy season, but again horizontal precipitation appears to be present during dry periods. For example, Figure 5.7 shows the average results for all four altitudinal sites in Tierra Santa. The results from these four sites were combined, because no statistically significant difference was found due to altitude. In Tierra Santa, open-area precipitation and throughfall are very close during rainy periods, such as June 1995 through March 1996, but open-area precipitation is consistently higher, supporting the overall results found for all study sites in both countries. However, from January through April of 1995, average throughfall is higher than open-area precipitation. While this difference appears slight on the graph and was not found to be statistically significant, calculating average precipitation for the January through May 1996 windy and dry seasons, throughfall was found to be 45 mm. higher than open area precipitation, which represents a 5.84% increase in total precipitation. This additional water would translate into an additional 448 m^3 per hectare during this dry period.

Similarly, in Jimerito, horizontal precipitation occurred only during the early months of 1995, as shown in Figure 5.8. Although the rain gauges were established at two different altitudinal sites, these data were also combined, because no statistically significant difference was found due to altitude. Average throughfall from January through March was found to be 315 mm., compared to 283 mm. in the open areas, which represents 11.57% additional water or 327.10 m^3 per hectare. Interestingly, this fog drip does not occur during the driest months (April and May), and some of the extra water received between January and March is offset by vertical interception during this period. Calculating the net effect of horizontal precipitation for the whole windy and dry period of January through May 1995, throughfall is found to be 17 mm. or 4.38% higher.

Although horizontal precipitation was not found to increase total precipitation at a statistically significant level, its influence in offsetting canopy interception and perhaps increasing precipitation by approximately 5-6% at these windward sites, as indicated by the monthly averages, should not be undervalued, because once again it appears to occur when precipitation is lowest and water availability is most critical.

No evidence was found of horizontal precipitation in either Cerro Jilinco or Cusuco. In Cerro Jilinco, the variance between gauges was much higher than at any other site, perhaps due to strong winds on this ridge and peak, which are open to winds coming from all directions. Because, according to Weaver (1972), stemflow appears to be more important in the elfin forest than other types of cloud forest, not quantifying stemflow may have also contributed to this variance. Therefore, these data were only used in a broad, descriptive way, to make a small contribution to the very limited knowledge available about the park's dwarf forest.

In Cusuco, it was necessary to discard the first few months of data, because two standard rain gauges managed by DIMA and the Fundación were used as the open-area gauges, and the data were found to be unrealistically different (sometimes much higher and sometimes unrealistically lower), perhaps due to sampling error or the different designs of the gauges. However, none of the data indicated any signs of horizontal precipitation, which is not surprising, since this is a sheltered, leeward site.

5.1.6 Climate of Tierra Santa and Cusuco, Honduras

All of the climate data contradicted the horizontal precipitation findings, showing more frequent dense cloud cover, stronger winds and lower temperatures – all factors that should be associated with more horizontal precipitation – in Cusuco than in Tierra Santa, although there was no evidence of horizontal precipitation in Cusuco. During the 95/96 windy and dry seasons, a total of 121 days with heavy or moderate cloud cover were reported in Cusuco, while only 44 were reported in Tierra Santa. This difference is probably related to the difference in altitude of these two sites; Cusuco is located at 1600 m.a.s.l., while Tierra Santa is located at 900 m..

The difference in altitude certainly explains temperature differences. In Cusuco, mean monthly temperature during the study period was 19.3 °C, whereas in Tierra Santa it was 25.2 °C. In Tierra Santa, average monthly maximum temperature reached a peak of 39 °C in September and average minima dropped to 15°C. in January, while in Cusuco these extremes were 36 °C. and 1 °C. in January and March, respectively. Maximum temperatures were found to be quite similar for the two sites throughout the year, but minima were clearly quite different.

In Cusuco, winds come predominantly from the north, with velocities between 1.5-3 m/s, whereas in Tierra Santa they come predominantly from the southeast, with velocities between 1-1.5 m/s. During the rainy season, especially July and August, in Cusuco wind speeds reach 3-4 m/s, whereas they are calm in Tierra Santa, oscilating between 0-1 m/s.

Monthly mean relative humidity is 90% in both sites, reaching lows in Cusuco of 43% in January and highs of 100% during at least one day each month, and for several days in May. In Tierra Santa, relative humidity was much higher in the rainy season, reaching 100% on several days, whereas during most of the dry season it oscillated between 50% and 80%.

5.2 IMPACT OF LAND USE ON STREAMFLOW

5.2.1 Honduran Paired Basins

Comparing streamflow for the pair of small basins in Tierra Santa (in Honduras) indicated that streamflow increased more quickly, in short, dramatic peaks in the deforested basin, as shown in Figures 5.8 and 5.9. Figure 5.8 provides results for July through October 1995. During this period, streamflow data were collected every four days; after this, they were taken daily. Although this sampling intensity is very low, the data clearly indicate a strong difference in streamflow. Because the rainy season was particularly strong during this period, these small basins received 2,317 mm of precipitation during these four months, and in the deforested basin, it appears that most of this water resulted in heavy storm runoff. Meanwhile, streamflow from the forested basin remained surprisingly stable, suggesting high infiltration and subsurface flow that is vital for the maintenance of mountain springs and flow during dry periods.

Statistical analysis showed the variance of the deforested basin to be significantly higher (at the 95% confidence level) than that of the forested basin throughout the study period. Most of the short peaks of storm runoff shown in the deforested basin can be considered water that is lost from possible human use, because it is available only for a very short time, it travels at high velocity, and it is apt to pick up a heavy load of sediment, lowering water quality, degrading stream habitat and causing siltation of dams, rivers and coastal areas downstream. Under severe storm conditions, this water could even cause flooding downstream.

Figure 5.8 Comparison of Rainy Season Streamflow, Tierra Santa

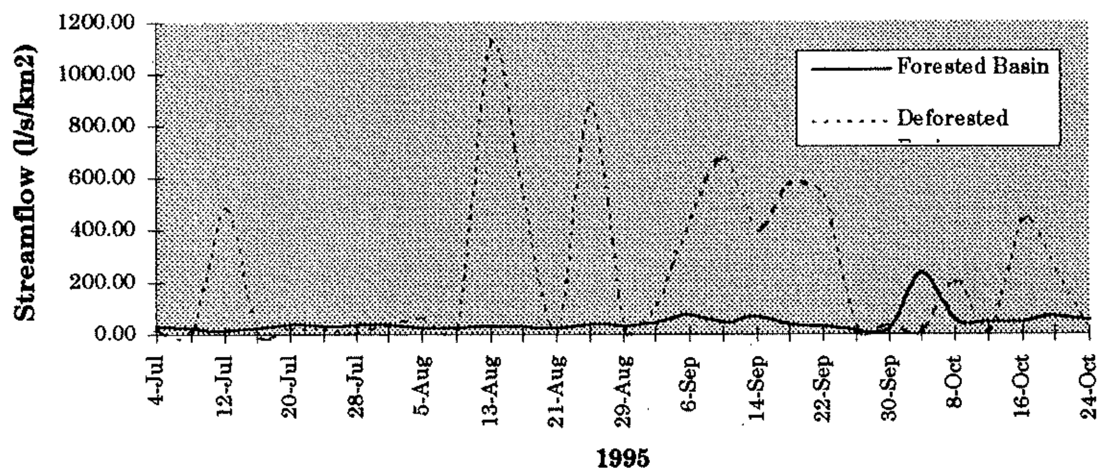


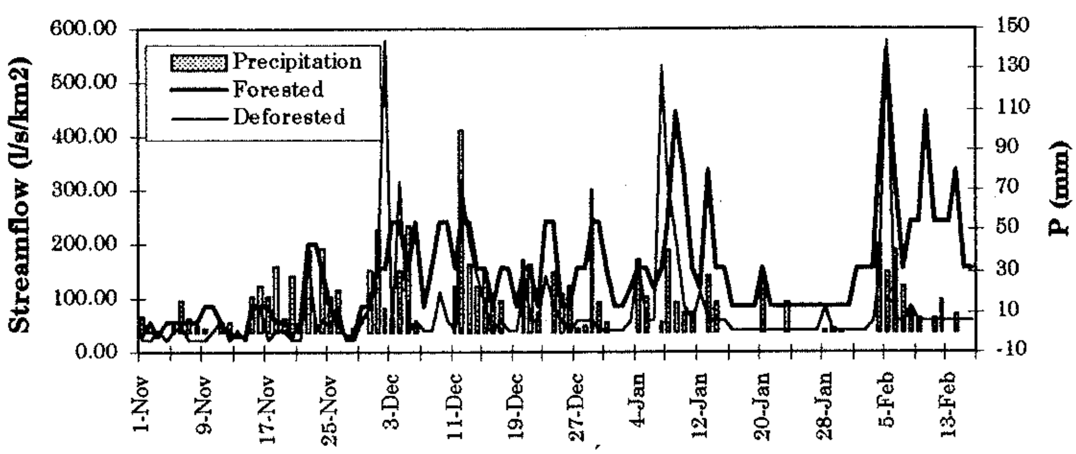
Figure 5.9 compares streamflow in this pair of basins between November and mid-February, during which time daily streamflow measurements were taken. During these 3.5 months, Tierra Santa received 1,377 mm of precipitation. Estimating water yield from these daily measurements, the deforested basin produced approximately 755,000 m3 of water, while the forested basin produced about 1,376,000 m3. This contrasts strongly to the previous period (July-Oct), during which total precipitation was 2,317 mm and the deforested basin produced 1,407,000 m3 and the forested only 446,000 m3. These data provide strong evidence that during very rainy periods, water yield is much higher in the deforested basin, but during drier periods, the higher baseflow of the forested basin produces higher yield.

During the entire dry season, streamflow in the deforested basin represented an average of 47.63% of the flow of the forested basin. Although these must be considered rough estimates of stream yield, because they are not based on continuous stream gauge measurements, nevertheless the differences in the hydrologic response of these two basins appear very clear.

Throughout almost all of the study period, baseflow (flow fed by groundwater rather than storm events) is higher in the forested basin than the deforested one. It appears that the deforested basin has lost a high proportion of its moisture storage capacity, a common phenomenon on steep, eroded and compacted soils, that is documented in the literature.

As can be noted in Figure 5.9, the correlation between precipitation and streamflow is not always strong. This is because precipitation was only measured in one site, below the basins, so precipitation events occurring at the top of these basins (about 150 m. higher) would not have been measured. Also, because streamflow was only measured once per day, some quick peaks were not captured.

Figure 5.9 Precipitation and Streamflow, Tierra Santa

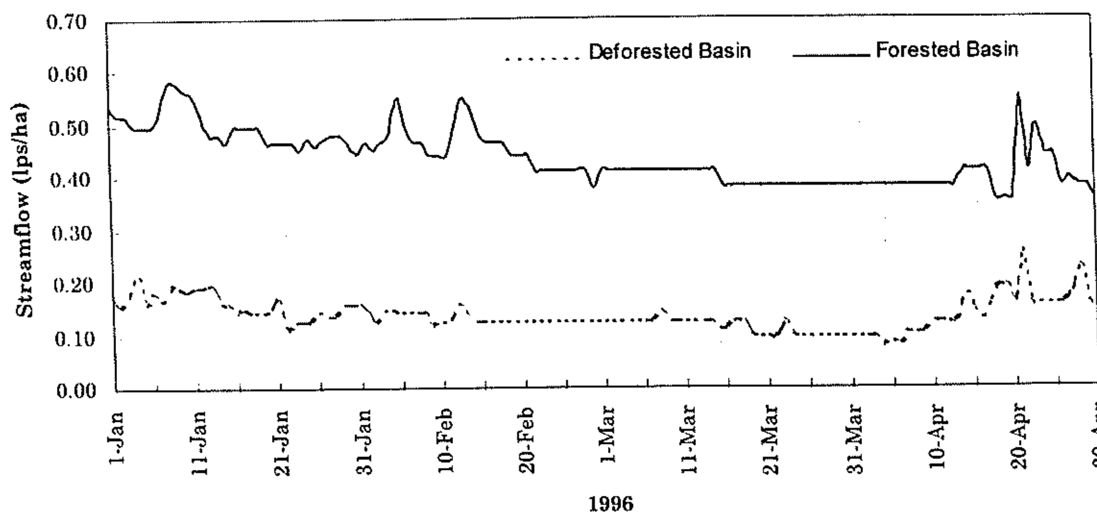


5.2.2 Guatemalan Paired Basins

In Guatemala the paired basins were established in late 1995 and therefore only dry season data can be analyzed. Data for January through April 1996 are presented and discussed. Because it was not possible to locate an adjacent pair of basins with contrasting land use, it was necessary to establish this portion of the research in a pair of basins located in different watersheds, as shown in Figure 5.1. These areas may have some natural differences; nevertheless, the goal of this research is to identify and characterize significant differences in the hydrologic response of basins as a result of deforestation.

As can be observed in Figure 5.10, baseflow is notably higher in the forested basin, which showed minimum flow of 0.36 lps/ha., in comparison with the deforested basin, in which minimum baseflow was 0.08 lps/ha.. Throughout the dry season, baseflow in the forested basin was found to be 68.1% +/- 1.15% higher than that of the deforested basin. Because baseflow represents groundwater flow, this difference suggests a higher infiltration capacity on the soils of the forested basin.

Figure 5.10 Comparison of Dry Season Streamflow in Guatemalan Paired Basins



It is important to take into account that the difference in streamflow between the two basins is not solely due to the difference in land use, since other factors such as physical characteristics, climate, geology, soils, altitudinal range and others all influence hydrologic response. The importance of these factors cannot be fully evaluated without specific studies.

On a general level, as can be observed in Table 5.3, the two basins are very similar in many of their principal characteristics. They are located in the same life zone and have the same general climate and geology and similar soils. However, their altitudinal range varies somewhat, and it must be taken into account that much of the information provided below was taken from general reconnaisance studies and may vary strongly on the scale of microwatersheds, especially in terms of climate. Because of the lack of such information, it is necessary to continue data collection to establish if a significant difference in precipitation exists between the two basins, in which case specific statistical analyses would be necessary to compare streamflow in terms of hydrologic response and not absolute numbers.

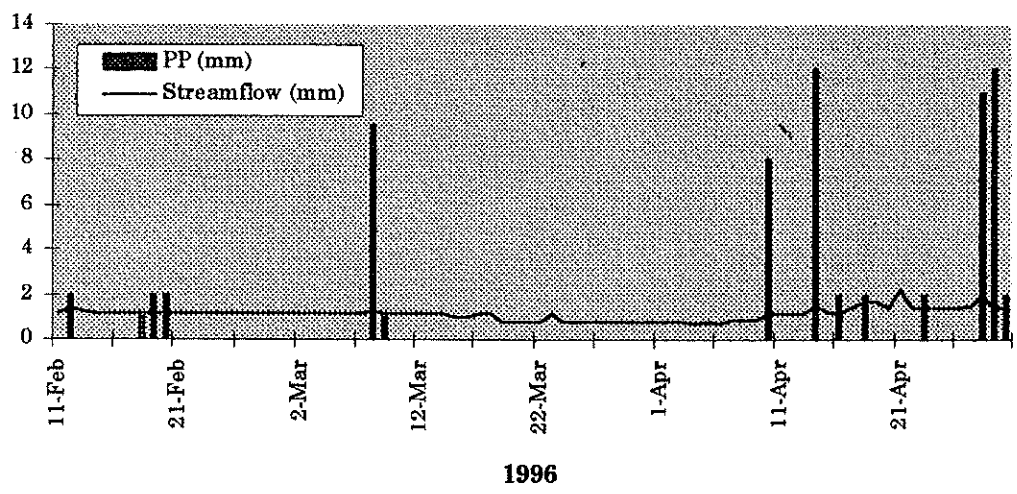
Table 5.3 Principal Characteristics of Guatemalan Paired Basins

Characteristic	Deforested Basin	Forested Basin
Altitude	1400 - 2120 m.	1900 - 2400 m.
Drainage size	150 ha.	196 ha.
Climate (1)	Somewhat warm, with benign winter and without a well-defined dry season	Somewhat warm, with benign winter and without a well-defined dry season
Holdridge Life Zone (2)	Subtropical Wet Forest	Subtropical Wet Forest
Soils (3)	Deep, well-drained soils, with silt loam texture, fine-grained structure. Subsoil below 1 m. clay with friable structure.	Deep, well-drained soils, with silt loam texture, granular structure. Subsoil silty clay with blocky structure.
Geology (4)	Predominantly Metamorphic Rocks, phyllite chloritic and granitic schists, gneiss of quartz-mica-feldspar and marble	Predominantly Metamorphic Rocks, phyllite chloritic and granitic schists, gneiss of quartz-mica-feldspar and marble

References: (1) Instituto Geográfico Nacional, Guatemala. 1975. (2) De la Cruz, 1982. (3) Simmons, Tarano y Pinto. 1959. (4) Instituto Geográfico Nacional, Guatemala. 1975.

Precipitation measurements were initiated in February 1996, to allow the comparison of the hydrologic response of each of the basins, and this data is analyzed through April 1996, representing the driest period of the year. In general terms, streamflow is quite stable during this period of minimum flow (primarily baseflow) and it appears that a relatively significant accumulation of precipitation is needed to saturate the soil pores (which are dry during this season) to the extent that one can observe a hydrologic response to a rain event.

Figure 5.11 Relation Between Precipitation and Streamflow, Guatemalan Deforested Basin

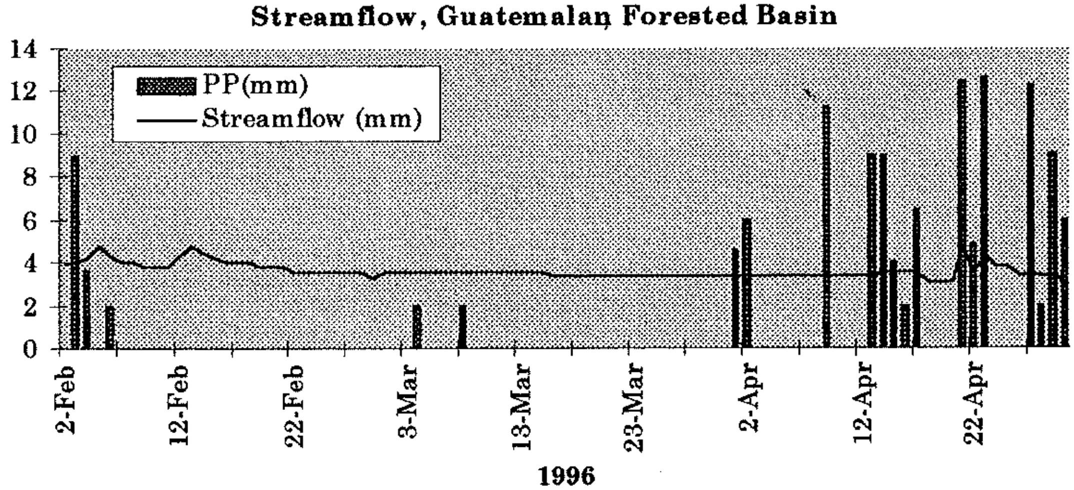


As can be observed in Figure 5.11, the deforested basin does not respond to precipitation events until the 14th of April, when a small increase can be observed as a response to a 11.2-mm. rainfall, that occurred when the soil was already wet due to a rain three days earlier. Figure 5.12 shows that streamflow is also very stable in the forested basin. Like the deforested basin, the forested basin receives very little precipitation until April. In this case, a hydrologic response is observed on April 21st, after a 12-mm rain event that followed a previous accumulation of 30 mm. between April 13-17, during which time streamflow remained stable.

It is important to mention that on a few occasions streamflow increases without a corresponding rain event to explain it. Once again, precipitation is being measured in only one place in each basin, within 200 m. distance of each weir. Taking into account the sizes of these basins (150 and 196 ha.) and their altitudinal ranges (extending 500 to 700 m. in elevation), it is quite probable that some precipitation events will occur in upper portions of the basins that will not be measured by our gauges.

Although the above information appears to suggest that the forested basin has a higher infiltration capacity and maintains higher and more stable baseflow, clearly, long-term data and especially data from a rainy season is needed to draw stronger conclusions about the hydrologic response of these two basins. Rainy-season data would also test the theory that forests decrease surface runoff during heavy precipitation events. Also, it is strongly recommended that an effort be made to establish another pair of basins, to account for natural variation that could heavily influence these results. The above analysis should be considered a very preliminary analysis intended to attract further interest in these significant relationships.

Figure 5.12 Relation Between Precipitation and Streamflow, Guatemalan Forested Basin



CHAPTER 6: SOCIOECONOMIC ANALYSIS OF WATER USED FOR IRRIGATION

Because agriculture represents the base of the rural economy in the arid Motagua Valley, most of the rivers on the southern side of the Sierra are used very intensively for irrigation. Three components of the research focused on determining the socioeconomic value of this water: measurements of water use, a survey about irrigation water use, and photointerpretation of current land use in each of the watersheds. Because they are very interrelated, the results from these three components are presented and discussed together, first for the Jones watershed and then for Hato. Then the survey results for both watersheds are combined for further analysis, to identify common factors affecting agricultural productivity and irrigation efficiency and to predict the effect of changes in the system.

6.1 JONES WATERSHED RESULTS

6.1.1 Land Use and Description of Irrigation System

Figure 6.1 shows current land use in the Jones watershed, based on photointerpretation of 1995 aerial photos. As one can see, a major proportion (59%) of this 93-km^2 watershed is still forested, with broadleaf cloud forest and mixed forest protecting the headwaters of most of the rivers and 3,335 hectares of pine forest at middle elevations. However, it is clear that parts of the upper basin are used for dry pasture and agriculture. In addition to the 654 hectares in the upper portion of the Rio Lima and Rio Blanco basins (in the middle of the watershed) that are currently used for pasture, the 564 hectares of secondary brush and young regeneration areas (classified as *matorral*) in the upper Rio Cañas and Rio Colorado basins (to the west) indicate that this area has been quite recently used for pasture or agriculture. Much of the *matorral* in the upper Rio Cañas basin is located in areas called *El Chaguite* and *Montaña El Imposible*, where the brush is cut and burned and the land is used for subsistence agriculture by farmers who live in Jones but spend several months of each year living at 2000 m. elevation, in simple huts, tending corn planted on what used to be cloud forest.

Agriculture, which represents the foundation of the rural economy in the Motagua Valley, depends heavily on irrigation, especially during the dry season that extends from November to mid-May. Because irrigation is conducted by

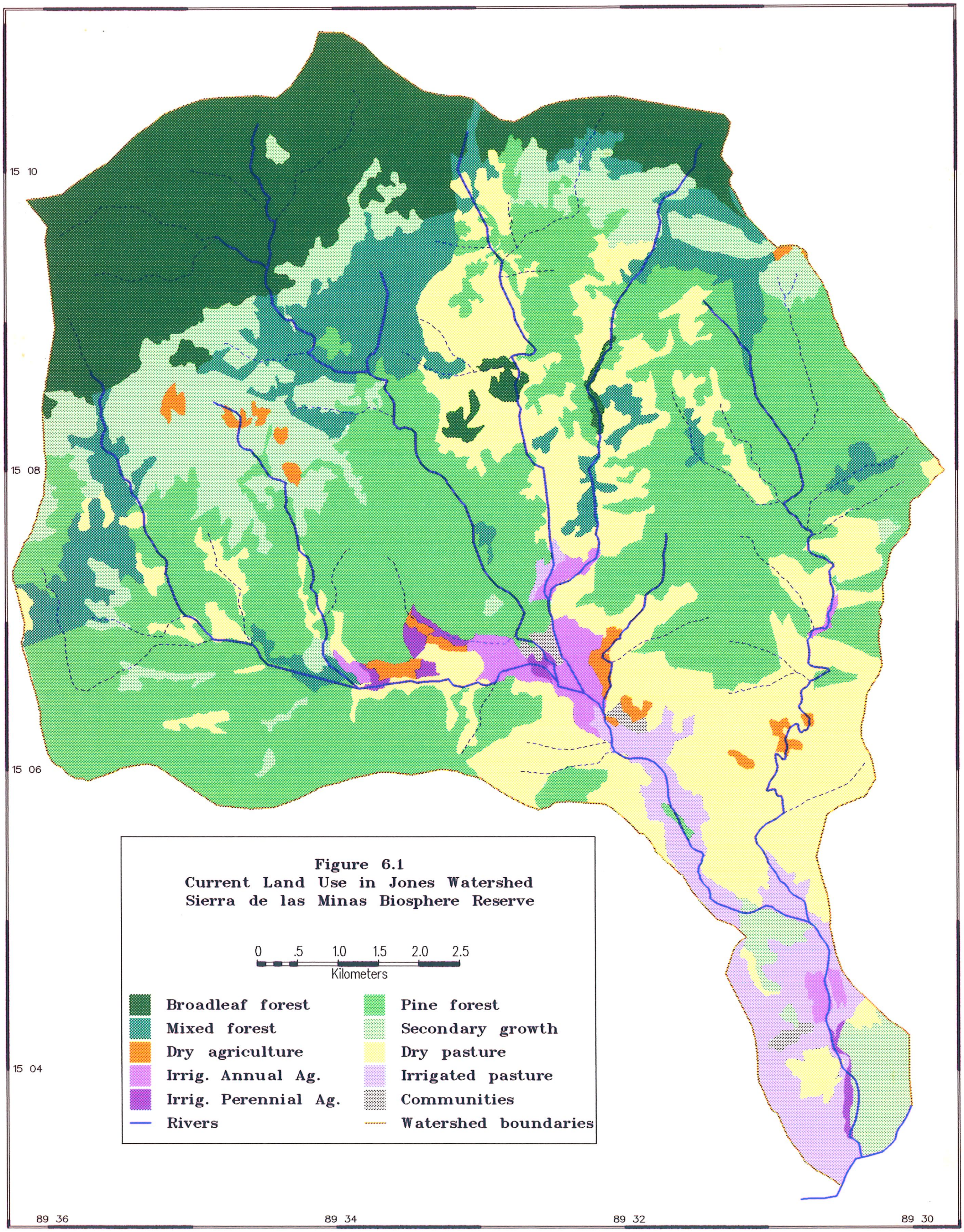


Figure 6.1
Current Land Use in Jones Watershed
Sierra de las Minas Biosphere Reserve

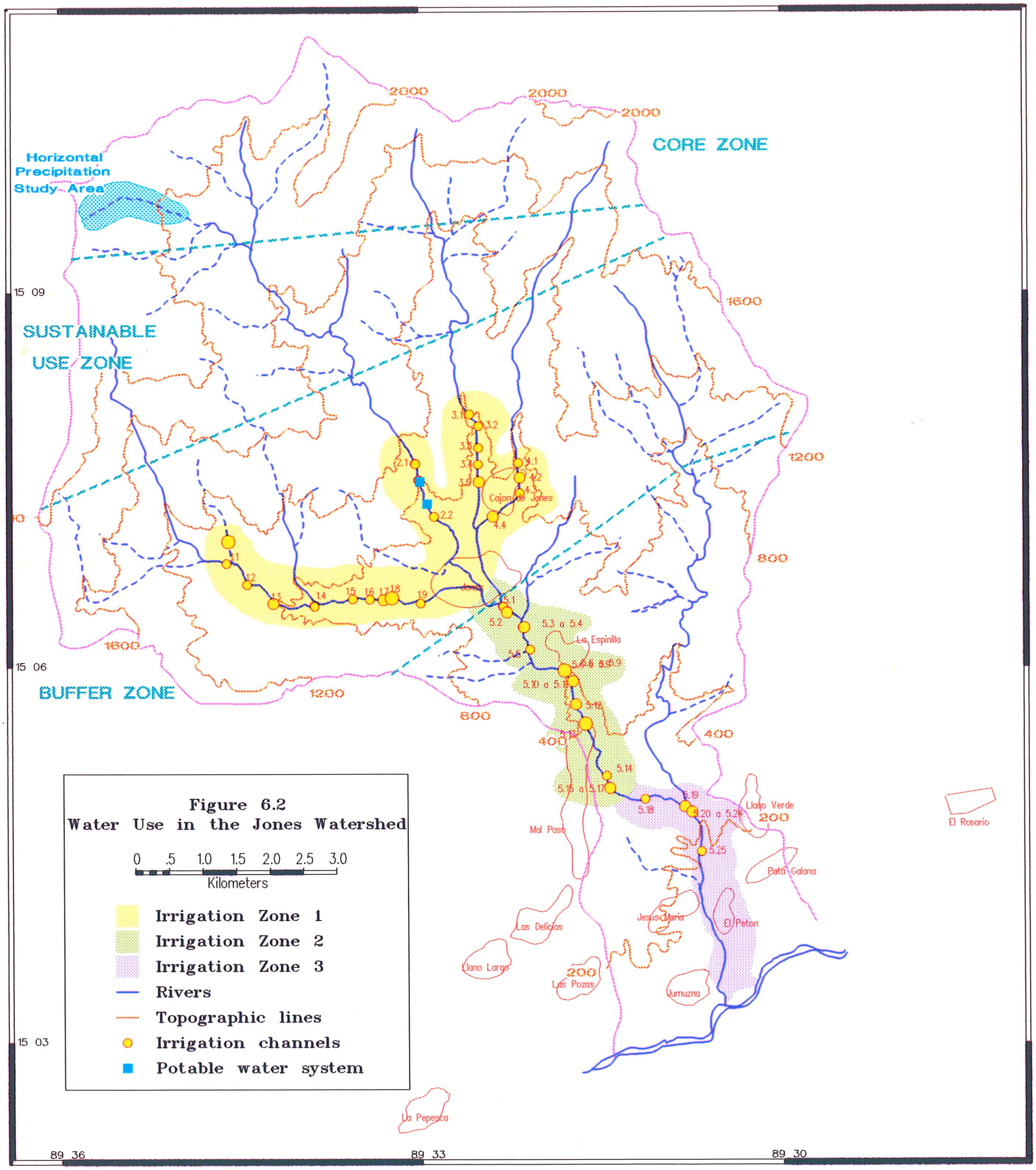


Figure 6.2
Water Use in the Jones Watershed

gravitation, through rustic irrigation channels, all irrigated land is concentrated around the rivers. As shown in Figure 6.2, the Jones watershed has a total of 50 irrigation channels, locally called *tomas*, that provide water to a total of 421 parcels of land. The number of parcels of land irrigated by each *toma* vary from 1 to 31, and the size of each parcel varies from .04 to 67 hectares. One can see in both Figure 6.1 and 6.2 that irrigation is concentrated in the middle and lower basin, due to the scarcity of precipitation in this zone and because the flattest, most fertile agricultural land is located in this region.

Irrigation begins at about 1000 m. elevation, because above this altitude precipitation is high enough to allow the cultivation of traditional crops such as corn and beans, and because there are no communities above Jones and El Cajón de Jones.

The *tomas* are simple systems that have been used for centuries. Rocks are piled up in the streambed to create small dams and divert streamflow through a trench that runs almost parallel to the river, on a slight elevational gradient. By placing rocks or branches in the trench and removing soil from the outside wall, water can be diverted from the irrigation channel onto agricultural land located between the channel and the river. The *tomas* are maintained by the farmers themselves, who in 1994 spent Q. 31 worth of labor on their maintenance in zone 1 and Q. 200-233 worth of labor on their maintenance in zones 2 and 3.

In Figure 6.2 one can see that some of the tomas irrigate land in towns located outside of the watershed, such La Pepesca, Llano Largo, Las Delicias, Las Pozas, El Rosario, and parts of Mal Paso and Llano Verde. These communities were not included in the photointerpretation, because it would have been difficult to distinguish between land irrigated with Jones River water and land irrigated with water taken from the rivers and streams in the two adjacent watersheds.

Both the photointerpretation and survey data demonstrate that pasture is the major land use in this watershed, on both irrigated and dry land. However, the survey data was used to estimate the quantity of irrigated pasture and agricultural land, because of the need to take into account the land in adjacent basins.

Most of the information about the dynamics of this system was obtained through the survey, in which approximately 15% of the farmers were interviewed in each of three zones. Figure 6.2 shows the section of the rivers from which water is diverted to the irrigated land in each zone but obviously does not cover all of the land in that zone since some of it is dry land and, as discussed above, some of it falls outside of the watershed. The altitudinal ranges of the zones are 580-900 m. in zone 1, 390-540 m. in zone 2, and 210-340 m. in zone 3. In the Jones watershed, approximately 89% of the farmers interviewed were men and the average age was 60. Almost half were Catholic and 27% Evangelical. These farmers have received very little formal education; 33% have never been to school and 34% have only studied through third grade. None have received more than a sixth-grade education.

As Table 6.1 demonstrates, land tenure varies between the zones, with larger average land ownership in the lower part of the basin. The average size of an irrigated parcel of land in zone 1 is 1.18 hectares, whereas it is more than 10 times that size in zone 3. The average size of a rain-fed, or dry, parcel of land increases in a similar way from 2.3 hectares in zone 1 to 10.9 in zone 2 and 22.44 in zone 3. It should be noted that, because of the relatively small size of this watershed, in some cases a farmer who lives and owns irrigated land in zone 2 or 3 owns dry land that is actually located in zone 1. Because of the number of local names used by farmers and their lack of familiarity with maps, the research team had difficulty trying to locate the dry land within one of the three zones. Because of this, the dry land is assigned to the same zone in which the farmer's irrigated land is located, and it is likely that the amount of rain-fed agricultural land in zone 1 is underestimated, while that of zones 2 and 3 is overestimated.

Table 6.1 Average Land Ownership, Jones Watershed

	Irrigated Land (ha.)	Rain-fed Land (ha.)
Zone 1	1.18	2.30
Zone 2	9.03	10.90
Zone 3	12.56	22.44

The primary land use throughout the Jones watershed (on both irrigated and dry land) is pasture, especially in the middle and lower parts of the basin, as shown in Figure 6.1 and Table 6.2. Extrapolating from the survey, it is estimated that in zone 1, 55 hectares of irrigated land are used for pasture, while 29 are in perennial agriculture and 13 in traditional agriculture. Rain-fed or dry land in zone 1 includes 291 hectares of pasture and only 7 of traditional agriculture and 1.5 of perennial agriculture. In zone 2, 587 hectares of irrigated land are used for pasture and 12 for traditional agriculture, while 1,619 hectares of dry land are in pasture and only 12 in traditional agriculture. In zone 3, 659 hectares of irrigated land are in pasture and 51 in traditional agriculture, while all 1,388 hectares of dry land are in pasture.

Almost all of the farmers in Jones irrigate their land during the second half of the dry season, from February through April. The seasonality of irrigation is shown by Figure 6.5, in which the percentage of farmers irrigating their land rises from 7% in August and September to 94% in March and April. From June through December, almost no irrigation takes place in zone 1, but pasture and

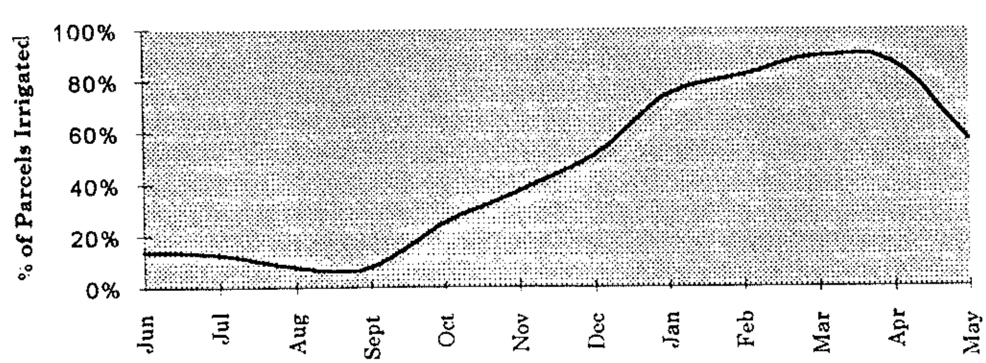
Table 6.2 Land Use in the Jones Watershed

	Irrigated Land			*Dry (Rain-Fed) Land*		
	Annual Trad. Ag.	Perennial Ag.	Pasture	Annual Trad. Ag.	Perennial Ag.	Pasture
Zone 1	13.44 +/- 3.21	29.30 +/- 16.68	54.86 +/- 34.84	7.35 +/- 3.44	1.5 +/- 1.59	290.78 +/- 177.90
Zone 2	11.67 +/- 5.54	---	586.51 +/- 104.04	11.67 +/- 5.54	---	1619.08 +/- 849.81
Zone 3	51.47 +/- 23.05	---	659.19 +/- 130.31	---	---	1387.92 +/- 874.40

some agricultural land is irrigated in zones 2 and 3. Irrigation of agricultural land and pasture in zone 1 begins in January, intensifies through April in all zones and drops off in May.

When asked if water is always available for irrigation when needed, 78% of the farmers in zone 1 and 85% of those in zone 2 said yes, but only 55% of those in zone 3 responded affirmatively. The two principal reasons for the scarcity of water were, first, that streamflow is too low, and second that too many other farmers use the irrigation channels. Interestingly, irrigation is organized through informal agreements between the farmers along almost all of the irrigation channels in zones 2 and 3; each farmer is assigned a period of time to irrigate each week or every two weeks, and all of the farmers adhere to this schedule, even if their time slot is in the middle of the night. However, only 13% of the farmers in zone 1 are organized in this way; most claim that whoever gets up earliest in the morning has the right to irrigate for as long as she or he wishes. It is quite likely that regulation of water use is not needed as much here, due to the relative abundance of water.

Figure 6.3 Timing of Irrigation, Jones Watershed



In zones 3 and 2, 85% and 63% of the farmers would like to have more water for their land, whereas only 35% of those in zone 1 expressed a desire for more water. The farmers were asked to suggest actions that could be taken to increase the amount of water in the irrigation channels. Of those who responded, the most common suggestions were to reforest or improve resource management and to improve organization of use of the tomas, and a few farmers suggested reconstructing the *tomas* or purchasing water pumps.

Most of the farmers throughout the watershed expressed support for conservation and many made a connection between forest protection and water availability. A total of 91% of the farmers said that they favor forest protection, while the other 9% did not answer this question. Their most common reason for supporting forest protection was that they believe that forests protect water resources. Many also believe that deforestation is bad in general.

Concern about water availability can be explained by the farmers' perceptions of changes in climate and streamflow. A total of 90% of the farmers claim that they have seen changes in climate during their lives. When asked to explain what changes they have seen, 46% said that the weather has gotten hotter, 47% said that it rains less, and 4% said that the dry season has gotten longer. Perceptions of changes in weather were strongest in the lower portion of the watershed, where 60% said that the weather has gotten hotter and that it rains less.

When asked about changes in streamflow, 77% of all of the farmers said that streamflow has decreased during their lifetimes. As shown in Table 6.3, 95% of the farmers in zone 3 perceived decreases in streamflow, while only 61% of those in zone 1 perceived decreases. When asked the cause of changes in streamflow, 55% of the farmers in zone 3 and 52% of those in zone 2 attributed the changes to deforestation, while 15% and 11% in the same zones mentioned longer dry seasons and less rain, as shown in Table 6.4. More than half of the farmers have also noticed pollution of the water used for irrigation, and 34% attribute this to sewage.

Table 6.3 During your life, do you believe that streamflow has increased, decreased, or remained the same?

	Zona 1	*Zona 2*	*Zona 3*	*Total*
Decreased	61%	78%	95%	77%
Increased	4%	4%		3%
Remained the Same	35%	15%	5%	19%
No Response		4%		1%

Almost all of the farmers are aware that cutting trees and hunting are prohibited in the core zone of the reserve, and more than half have noted changes in resource management since Defensores began working in this region. Although 33% of the farmers are not familiar with Defensores, another 47% said that deforestation has decreased and resource protection has increased due to Defensores' efforts.

Table 6.4 What has caused these changes in streamflow?

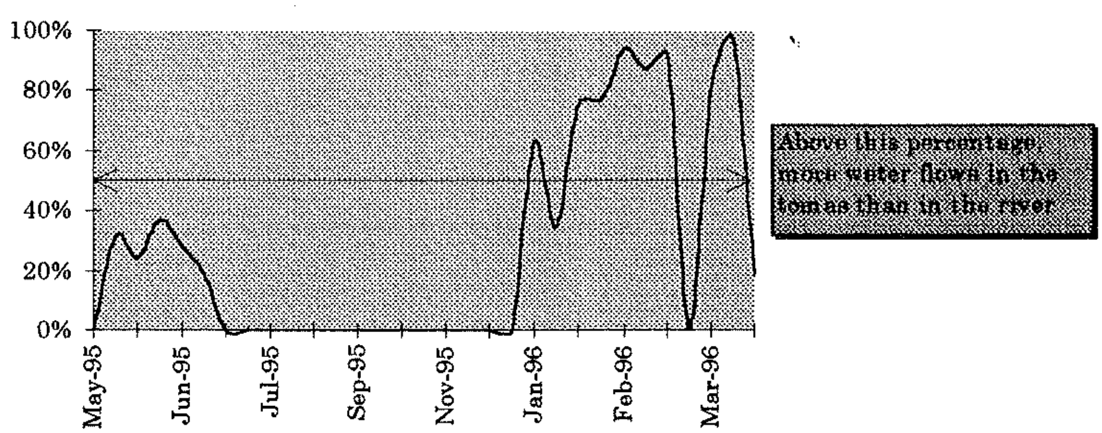
	Zone 1	*Zone 2*	*Zone 3*	*Total*
Deforestation	22%	52%	55%	43%
More irrigation and potable water systems	18%	4%	5%	9%
Longer dry season / less rain	4%	11%	15%	10%
God	4%	4%		3%
No Response / Don't Know	52%	26%	25%	34%

6.1.2 Quantification of Water Used for Irrigation

Measurements of streamflow and irrigation channel flow were taken in all three zones of Jones, including the measurement of nine tomas along the Cañas River in zone 1, nine tomas on the Jones River in zone 2 and six in zone 3. Data was collected for a full year in zones 1 and 2 and during the dry season in zone 3.

As can be seen in Figure 6.4, water diversion on the Cañas River, in zone 1 of Jones, occurs primarily between December and June, with the most intensive irrigation taking place in the second half of the dry season, from mid-January through April. During this period up to 80-95% of streamflow is diverted. From July to mid-December the irrigation channels are not used, because precipitation during the rainy season is heavy enough to meet crop needs.

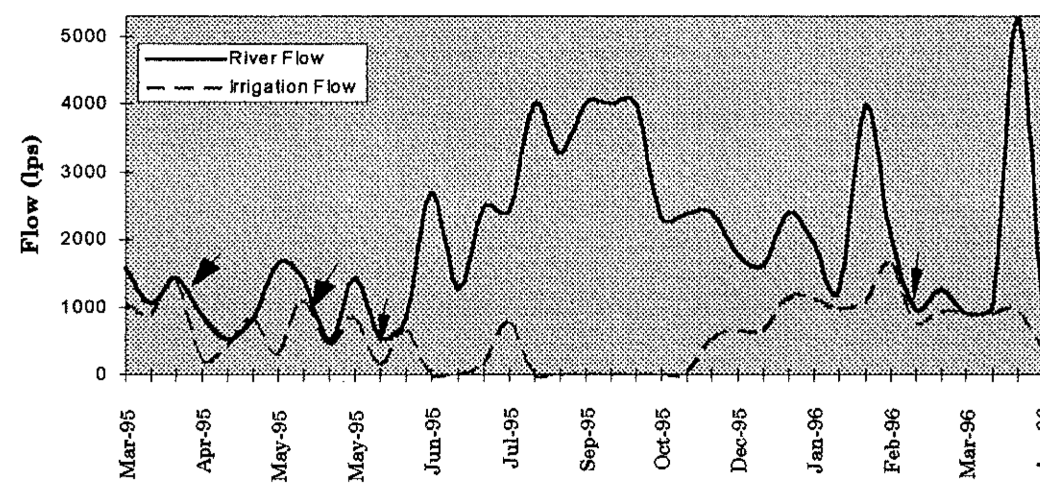
Figure 6.4 Percentage of Water Diverted for Irrigation, Canas River



Similarly, in zone 2 irrigation occurs primarily between November and June and during a short dry period in July locally called *canicula*. Water diversion reaches 80-97% in this zone during February and March.

It is important to mention that because irrigation is conducted by gravity, there is a certain proportion of flow that cannot be diverted, and the quantity of water that can be diverted fluctuates with the level of the river, as is shown by the arrows in Figure 6.5. Because the farmers in both zones 2 and 3 irrigate their land on a fixed schedule, surges in water flow benefit only those farmers who happen to be irrigating at the time of the surge, and in extreme cases such surges could cause damage due to erosion. Thus, water availability is a function not only of the overall quantity of water available, but also the evenness of the flow. Watershed management activities that protect the infiltration capacity of the upper watershed and stabilize the flow are valuable to these downstream users.

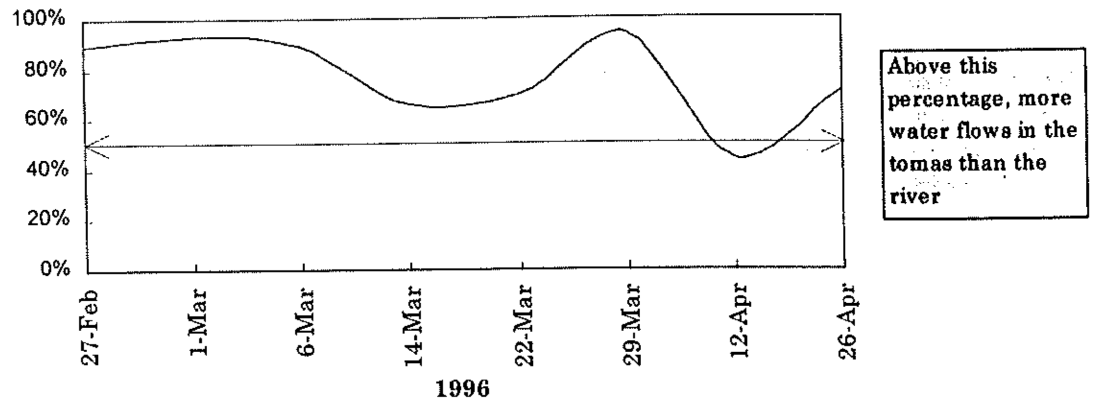
Figure 6.5 Water Diversion for Irrigation, Jones Zone 2



Water use is much higher in zone 2 than in zone 1, both in terms of the volume of water diverted and the period during which it is diverted. This zone is drier, more fertile and flatter, allowing more irrigation. Also, more water is available for diversion in zone 2, due to the confluence of the Cañas, Colorado, Blanco and La Lima Rivers that form the Jones River. During the critical part of the dry season, streamflow along this part of the Jones River varies from 900 to 3900 lps, whereas in zone 1 the Cañas River flow varies from 200 to 500 lps.

The bottom of the Jones watershed (zone 3) clearly has the lowest water availability, due to heavy upstream use. During the study period, streamflow varied from 80 to 500 lps, which is much lower than the 900 to 3900 lps flow observed during this period in zone 2. In this zone, water use is consistently high throughout the critical part of the dry season, with occasional reductions in use due to sporatic rains, as shown in Figure 6.6. Survey data indicated that some irrigation continues through the rainy season, because this region is very arid.

Figure 6.6 Percentage of Streamflow Diverted at the Peak of the Dry Season, Lower Jones Watershed



6.1.3 Land Value and Agricultural Productivity

It is clear that water is a very valuable resource in the Jones watershed. As Table 6.5 demonstrates, irrigated land has a market value 3.6 to 9 times as high as dry land. Not surprisingly, the most valuable irrigated land is found on the fertile alluvial plain in the middle and lower basin.

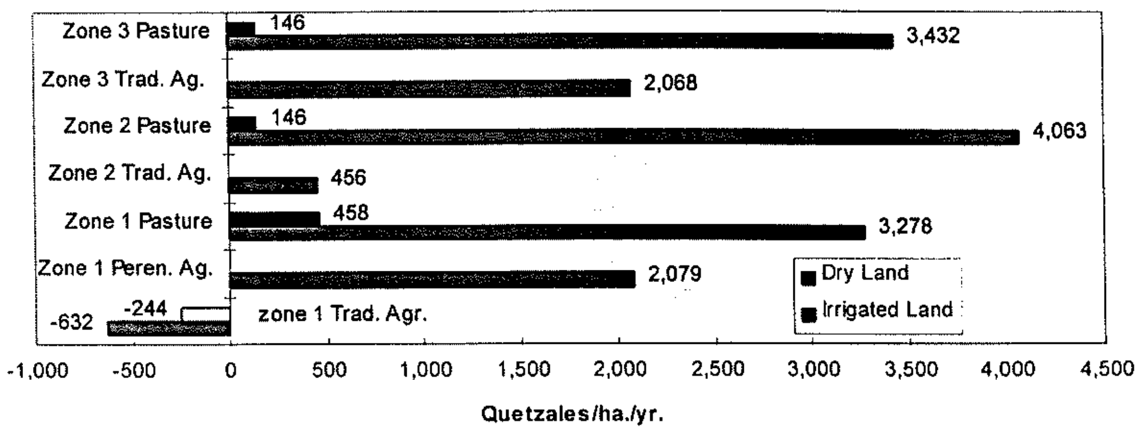
Table 6.5 Jones Land Value (Quetzales/ha. and $/ha.)

	Irrigated Land	*Dry or Rain-fed Land*
Zone 1	Q. 8,617.70 ($1,405.82)	Q. 2,391.90 ($390.20)
Zone 2	Q. 21,245.70 ($3,465.86)	Q. 2,552.20 ($416.35)
Zone 3	Q. 19,029.50 ($3,104.32)	Q. 2,100.00 ($342.58)

The value of water is also very clearly demonstrated through the difference in productive value of irrigated and dry land. In Jones, the productivity of cattle pasture is expressed in terms of the market value of the weight gained by the cattle grazing on each area of pasture. As shown in Figure 6.6, in zone 1 irrigated pasture is 7 times as productive as dry pasture, while in zones 2 and 3 it is, respectively, 27.8 and 23.5 times as productive. One of the farmers we interviewed stated very clearly that without irrigation it would be impossible to raise cattle in Jones.

Extrapolating the productivity values to the entire watershed, one finds that although the 1,406 hectares of irrigated land in the Jones watershed represent only 29.85% of all agricultural land and pasture, they produce annual net profits that total Q.4,989,343 ($813,922), that represent 89.74% of all agricultural profits in the basin. The 3,305 hectares of dry land in production produce only Q. 570,406 ($93,052).

Figure 6.6 Comparison of the Productive Value of Irrigated and Dry Land, Jones Watershed



Irrigated land is more valuable not only because it produces higher crop yields and supports more grazing, but also because it allows the production of crops that cannot be grown on dry land. In zone 1 of Jones, for example, perennial crops such as sugar cane and coffee that can only be grown on irrigated land are more profitable than traditional annual crops such as corn and beans. In zones 2 and 3, which are more arid than zone 1, dry land is used only for pasture and its productivity is very low compared to that of irrigated land.

Traditional subsistence crops, such as corn and beans, produced negative net profits in zone 1 in this economic analysis, because the analysis included labor costs that the farmers often do not actually pay. Subsistence crops are often tended by family members who earn no real wages but whose time must be calculated at market value in the analysis. Average gross earnings from traditional agriculture in zone 1 are Q. 2,196 +/- 1006 on irrigated land, while they are Q. 1,373 +/- 244 on dry land. This shows that irrigated land tends to produce higher yields, but because farmers tend to invest more time and inputs into irrigated land, net profits are more negative on irrigated land than on dry land. These negative net profits indicate a lack of economic opportunities and strong cultural traditions that guide agricultural activities; given the opportunity, these farmers and their family members would be better off economically if they worked for a real wage and purchased their corn.

Water use was estimated by combining the irrigation flow data with the number of hours the farmers said they irrigated. As can be seen in Table 6.6, the farmers cultivating annual and perennial crops in zone 1 use more than three times as much water as any other users. This suggests a large amount of waste and inefficiency in this relatively humid zone, aggravating water scarcity downstream. The amount of water used per hectare of pasture decreases as one moves down the watershed, while the productivity of the land remains relatively stable. The greatest additional productive value of water is obtained in zone 3, because water is used the most efficiently in this zone.

Table 6.6 Quantity of Irrigation and Additional Productive Value Due to Irrigation

	M3/Ha./Yr.	Additional Productive Value (Q./1000 M3 of Irrigation)
Zone 1 Annual Ag.	77,462 +/- 20,482	--
Zone 1 Perennial Ag.	77,003 +/- 2,066	26.99
Zone 1 Pasture	21,854 +/- 12,709	149.99
Zone 2 Pasture	14,100 +/- 4,194	288.15
Zone 3 Pasture	10,075 +/- 2,837	340.65

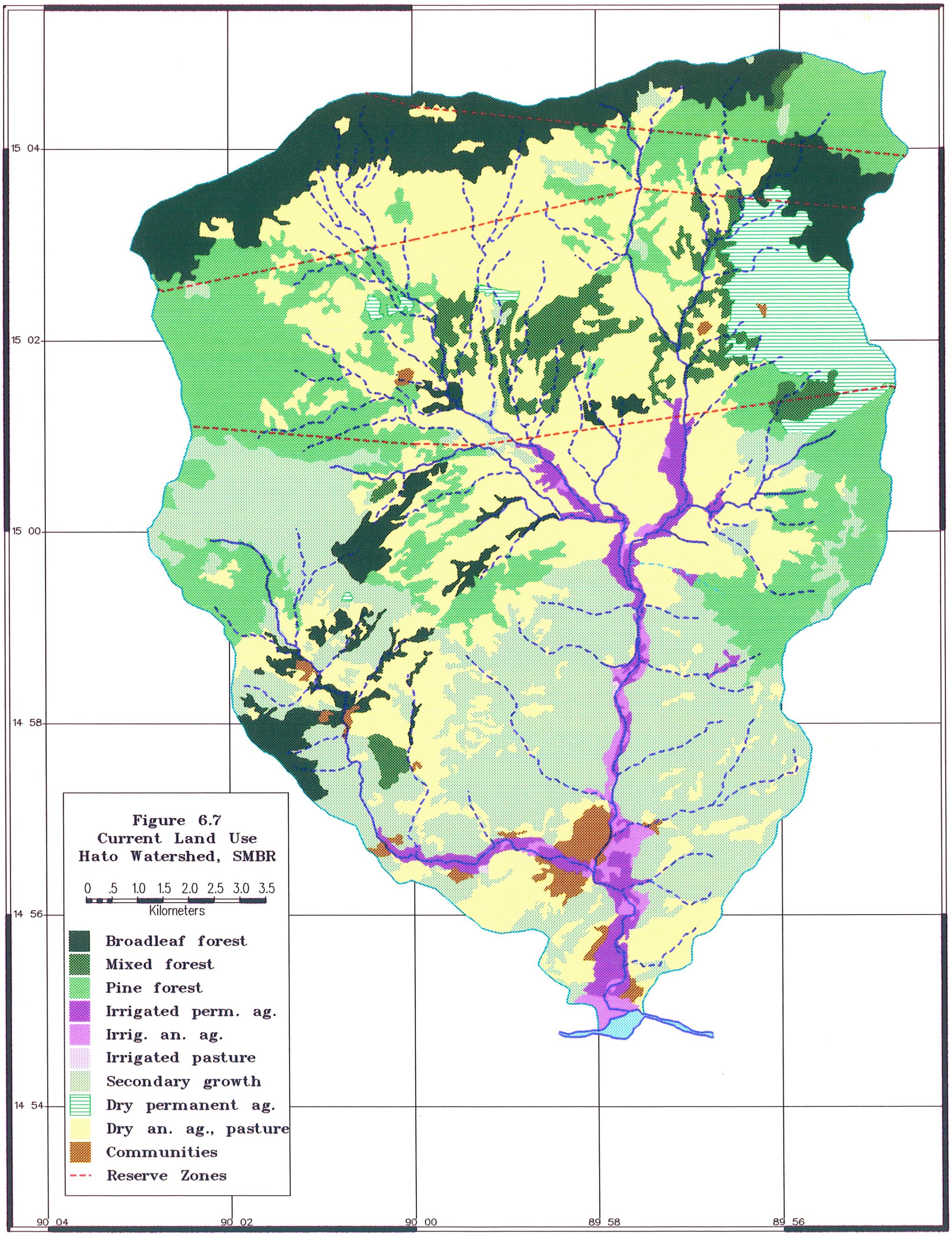
6.2 HATO WATERSHED RESULTS

6.2.1 Land Use and Description of Irrigation Systems

As seen in Figure 6.7, the Hato watershed has been more intensively settled and used than the Jones watershed, and currently only 34% of the 198-km^2 basin is forested. Although 32% of the land is classified as dry agriculture and pasture, the survey indicated that there is very little cattle in this watershed, and field visits show that much of this dry land is abandoned and unused, probably resulting from past degradation of these steep slopes and fragile soils. The central, upper portion of the watershed is heavily deforested and most of the intermittent streams in the headwaters of the Hato and Timiluya Rivers are not adequately protected.

Almost one quarter of the watershed is classified as secondary growth. In the lower basin, this is natural thorny scrub vegetation, but in the upper portion of the Aguahiel drainage area, this represents overgrown pasture and agricultural land.

Like Jones, irrigated land is concentrated along the principal rivers. However, here it is used almost entirely for annual agriculture (primarily traditional crops such as corn and beans) and perennial crops such as fruit trees and coffee.



15 04
15 02
15 00
14 58
14 56
14 54
90 04
90 02
90 00
89 58
89 56
Figure 6.7
Current Land Use
Hato Watershed, SMBR
0 .5 1.0 1.5 2.0 2.5 3.0 3.5
Kilometers
Broadleaf forest
Mixed forest
Pine forest
Irrigated perm. ag.
Irrig. an. ag.
Irrigated pasture
Secondary growth
Dry permanent ag.
Dry an. ag., pasture
Communities
Reserve Zones

Irrigated land represents only 3.57% of the land in this watershed, while all dry agricultural land represents 36.37%. The dry perennial agriculture in the northeastern portion of the basin is mostly shade coffee.

Unlike the Jones watershed, not all irrigation systems in the Hato basin are channels that move water by gravity. At the top of the watershed, in zone 1, all irrigation is done using hoses. Hoses are more efficient than channels, because water in the montane streams enters the hoses at high velocity and pressure, which can allow the water to be directed uphill or along flat or sloping topography. And, because the hoses can be moved, they can be used to irrigate a large area more evenly. Irrigation channels start at about 950 m. elevation and are used for irrigation in zones 2 and 3.

Figure 6.8 shows the location of irrigation channels such as those found in Jones; the 65 hoses used in zone 1 are not located on the map. The Hato watershed has 53 irrigation channels that provide water for 536 parcels of land along its two main rivers -- the Hato (to the East) and Timiluya (to the West) Rivers. The number of parcels of land irrigated by each channel varies from 1 to 78, and the size of each parcel varies from .04 to 5 ha., while parcels of dry land range in size between .08 and 43 ha.. The Aguahiel River was not surveyed.

The socioeconomic survey and measurements of water use for irrigation focused on the Hato River, from the headwater communities and farms of Albores, La Trinidad and El Carmen in zone 1 to the mid-elevation communities of Chanrayo, Puerta de Golpe and others, down to San Agustin de Acasaguastlan and other communities in the lower portion of the watershed. It should be noted that agricultural land use extends much higher in the Hato basin than in Jones and therefore the zones are not comparable. For example, zone 1 in the Jones basin extends from 580 to 900 m., whereas in Hato the altitudinal range is 950 to 1750 m..

Large landholdings, such as those found in the lower portion of the Jones watershed, are very uncommon throughout this basin, and very small parcels are quite common, particularly in zone 2. As indicated in Table 6.7, average land ownership is lowest in zone 2, where farmers own an average of 0.66 ha. of irrigated land and 1.27 ha. of dry land. Land ownership is highest in zone 1, at 3.95 ha. of irrigated land and 5.75 ha. of dry land.

Table 6.7 Average Land Ownership, Hato Watershed (ha.)

	Zone 1	*Zone 2*	*Zone 3*
Irrigated Land	3.95	0.66	1.15
Dry Land	5.75	1.27	5.25

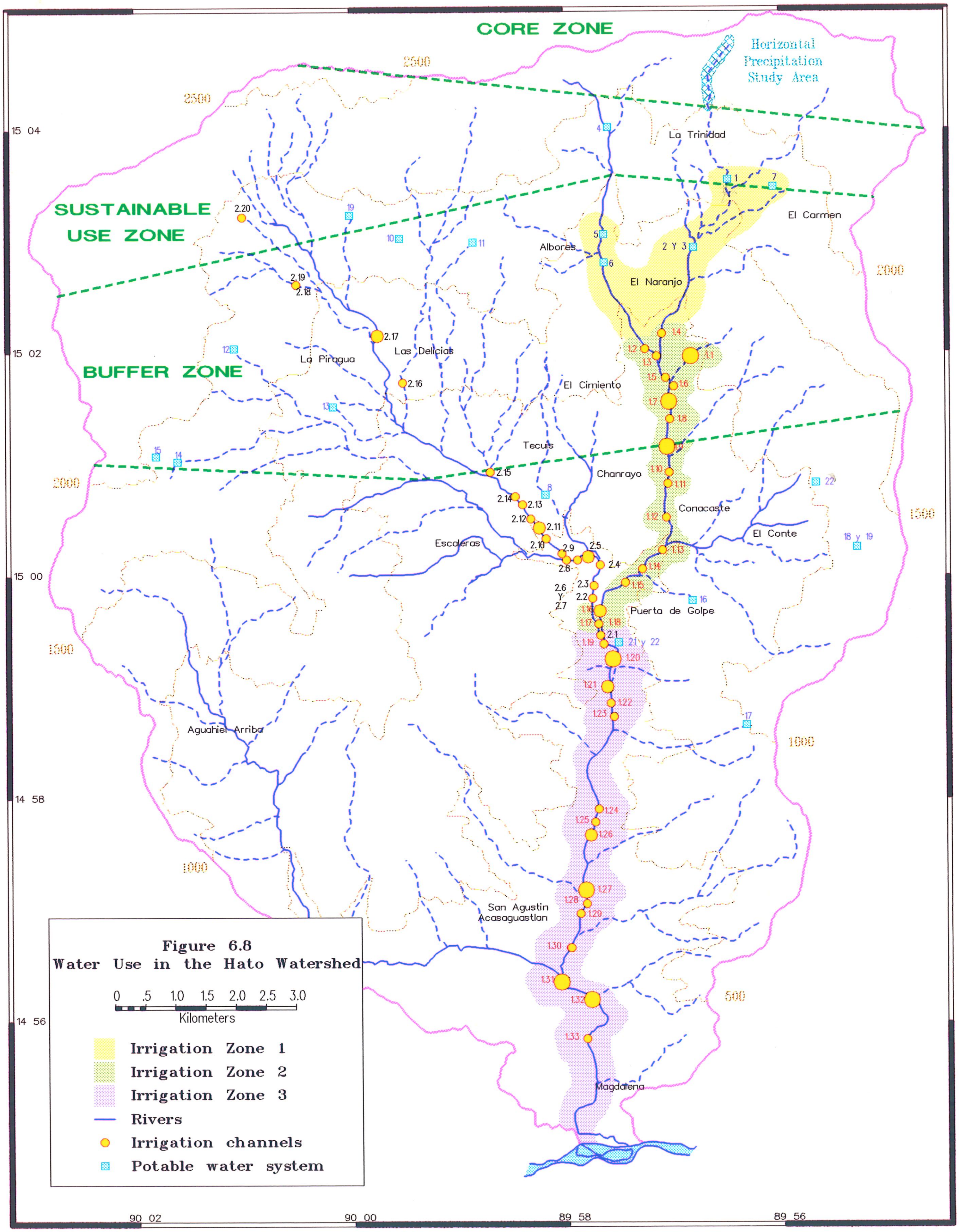


Figure 6.8
Water Use in the Hato Watershed

Approximately 84% of the farmers interviewed were men and the average age was 53. Eighty percent were Catholic, 6% Evangelical and 11% do not attend church. More than two-thirds of the farmers are literate, with the lowest literacy rate (56%) found in zone 2. However, as Table 6.8 demonstrates, 45% of all of the farmers have only the equivalent of a third-grade education, 31% have received no formal education at all, and only 4% have studied beyond 6th grade. The lowest level of formal education occurs in zone 2

Table 6.8 Education of Farmers, Hato Watershed

	Zone 1	*Zone 2*	*Zone 3*	*Total*
No Formal Education	17%	47%	18%	31%
1st-3rd Grade or Equivalent Literacy Program	33%	33%	60%	45%
4th-6th Grade	33%	9%	13%	12%
Junior High and High School	17%	2%	5%	4%
N/A		9%	5%	7%

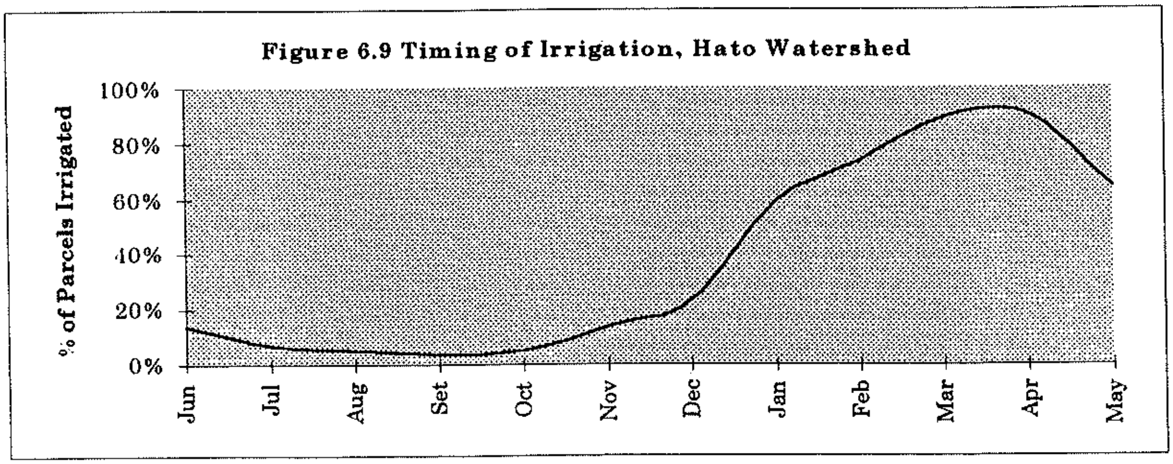
The primary land use throughout the watershed is traditional and perennial agriculture, with a small amount of non-traditional crops grown in zone 3. There is so little pasture in the Hato watershed that it was not included in this analysis. As shown in Table 6.9, irrigated land is used for traditional agriculture in zone 1, for perennial agriculture in zone 2 and for traditional, non-traditional and perennial agriculture in zone 3. In zone 1, corn and beans are grown on both irrigated and dry land, and, because of the high moisture in this zone, which ranges in altitude from 950 to 1750 m., coffee, cardamon and sugar cane are grown on dry land. In zone 2, mangos, zapotes, chicos, pacaya (palm fruit), citrus and other fruit trees, plus some coffee and sugar cane are grown on irrigated land, while dry land is used primarily for corn and beans, some coffee and firewood. In zone 3, fruit trees, corn, beans, tomatoes, hot peppers, cucumber, melons and tobacco are grown on irrigated land, while dry land is used for corn, firewood and some pasture.

Table 6.9 Land Use in the Hato Watershed

	Irrigated Land			**Dry (Rain-Fed) Land**		
	Annual Trad. Ag.	Perennial Ag.	Non-traditional	Annual Trad. Ag.	Perennial Ag.	Non-traditional
Zone 1	33.93 +/- 15.50	---	---	44.03 +/- 23.38	28.40 +/- 14.19	---
Zone 2	---	98.51 +/- 27.77	---	59.98 +/- 10.20	11.29 +/- 8.55	---
Zone 3	72.25 +/- 32.04	48.75 +/- 12.42	25.31 +/- 11.64	221.29 +/- 277.79	---	---

Farmers begin to irrigate their land at the beginning of the dry season, in November. As Figure 6.9 indicates, more than half of the farmers in the Hato watershed irrigate their land from January through May. The non-traditional crops grown in zone 3 provide an exception to this schedule, because they are grown from April to December, and a few farmers in zone 3 irrigate their traditional and perennial crops during the rainy season, when necessary.

Figure 6.9 Timing of Irrigation, Hato Watershed



A bit more than half of all of the farmers said that water is not always available for irrigation when needed, and 72% of the farmers in zone 2 expressed this concern. Half of the farmers in zone 1 and a quarter of those in zone 3 said that the principal reason for scarcity of water was that streamflow is low in comparison with the demand for water; in zone 2, a third of the farmers said that poor organization of water use is to blame. Unlike Jones, very little organization of water use exists in this watershed. There is no organization in zone 1, and only 5% of those interviewed in zone 2 claimed that the users of their *toma* are informally organized. In zone 3, 10% said that the users of their irrigation channel are informally organized and 30% said that a "water judge" regulates use of water along their *toma*.

Almost two-thirds of all of the farmers said that they would like to have more water for their property, including 74% in zone 2, 67% in zone 1 and 45% in zone 3. When asked what could be done to increase the quantity of water available, 16% of all of the farmers suggested reconstructing the *tomas*, while 13% (mostly in zones 1 and 2) suggested reforesting and improving resource management. In most cases, all of the water users contribute to the maintenance of the *tomas*, dedicating from 3.5 to 5.25 days (or Q. 43-59) at the beginning of the dry season to patching leaks along the channel and building dams to divert streamflow into the channel.

Almost all of the farmers support forest conservation, primarily because they believe that forests protect water. Many also said that they believe that deforestation is bad, in general. Although only 43% of the farmers had heard of Defensores, 90% knew that cutting trees and hunting are prohibited in the reserve. Of those who had heard of Defensores, a quarter believe that deforestation has decreased and that resource protection has increased since Defensores started working in the region, and 12% say that there is more environmental awareness.

Most of the farmers have noticed changes in climate and steamflow during their lives. More than four-fifths have noticed changes in climate, and when asked to explain these changes, 26% said that the weather has gotten hotter, 15% said that precipitation has decreased, and 11% said that the dry season has gotten longer. Interestingly, 90% have noticed decreases in streamflow during their lives. When asked to explain these decreases, as Table 6.10 indicates, almost half of the farmers blamed deforestation, while only a few mentioned more water use, longer dry seasons, and God's intervention. Almost two-thirds of the farmers have noticed pollution of irrigation water, primarily due to sewage pipes and sedimentation caused by landslides.

Table 6.10 What has caused the changes in streamflow (that you have perceived)?

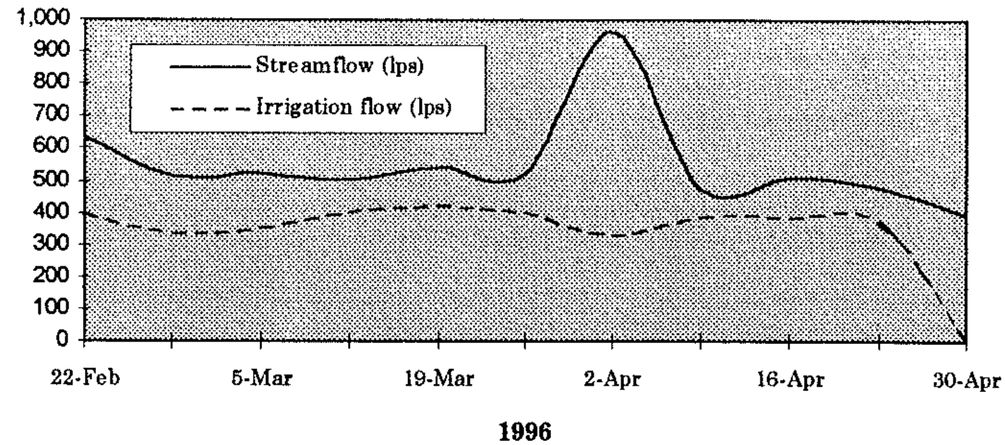
	Zone 1	*Zone 2*	*Zone 3*	*Total*
Deforestation	67%	44%	40%	44%
Don't Know		9%	8%	8%
More water use (for irrigation and potable water)	50%		5%	5%
Longer dry seasons		9%		4%
God		2%	3%	2%
No Response	17%	2%	10%	7%

6.2.2 Quantification of Water Used for Irrigation

Water use in zone 1 was found to be very low. There are 65 hoses used in zone 1, including both 1/2"- and 3/4"-diameter hoses. The flow through these hoses varies according to topography but average flow through each hose was estimated at 0.40 +/- 0.13 l/s. Estimating the impact of this water extraction along one of the streams in zone 1 (Quebrada Las Nubes) during the December-April irrigation period, total irrigation flow was found to vary from 8 to 23 l/s, while streamflow fluctuated from 167 to 533 l/s. Clearly, water use in this zone is minimal in comparison with water availability.

In the middle of the Hato basin, four irrigation channels were measured weekly during the peak of the 1996 dry season. As Figure 6.10 demonstrates, during most of this period, 60-80% of streamflow was used for irrigation, except on April 2, when some of the tomas were closed after a rain event. Irrigation is very seasonal in this zone. As can be seen, at the end of April, when the rains began, the tomas were closed and would remain closed during most of the rainy season.

Figure 6.10 Dry Season Irrigation, Middle Hato Watershed



In the lower Hato basin (zone 3), 12 tomas that irrigate 99 parcels of land were measured for a complete hydrologic year. As shown in Figure 6.11, although streamflow is clearly very high and water use very low between August and November, water use rose to 50-75% between January and April of 1996, quite similar to the proportion used in May 1995. The absolute quantity of water used in the lower basin exceeds that of the middle basin, because more water is available. During most of the dry season, streamflow in the middle basin fluctuates from 390 to 630 l/s, whereas in the lower basin it varies from 1080 to 1360 l/s., due to the additional flow from the Timiluya River. However, the percentage of water used in the middle basin (60-80%) is higher.

In comparing the two watersheds, water use is more intensive in the Jones basin, in relation to the amount of water available, but the quantity of water used per hectare irrigated (as well as the total quantity used) is definitely higher in the Hato basin. This is because the Hato basin covers 197.93 km2, which represents more than twice the size of Jones, which is 92.85 km2. Although forest protection is definitely lower in the Hato basin, the watershed drains a larger upland area, making more water available for irrigation in the lower basin.

6.2.3 Land Value and Agricultural Productivity

The value of water is demonstrated very clearly by the difference in land values and agricultural productivity. As Table 6.11 indicates, in zone 1 irrigated land

Figure 6.11 Irrigation in the Lower Hato Basin

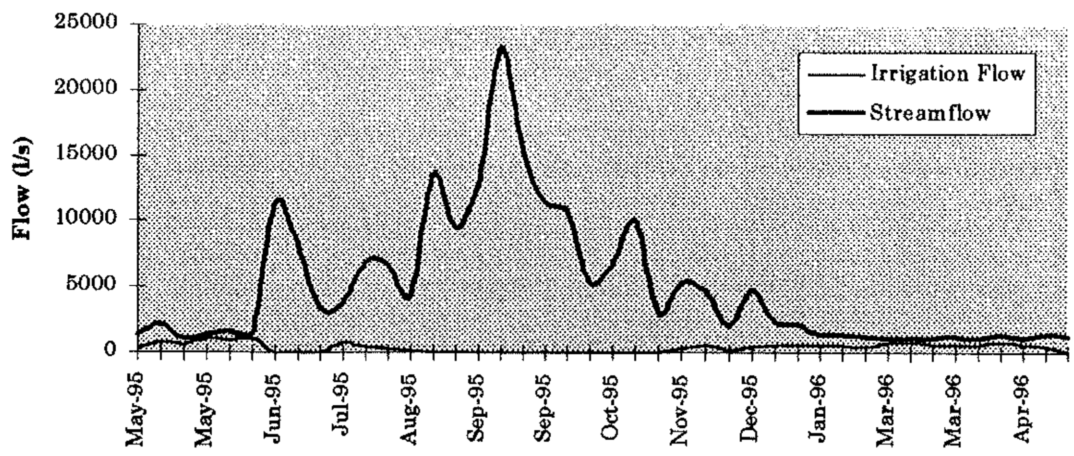


Figure 6.5 Irrigation in the Lower Hato Basin

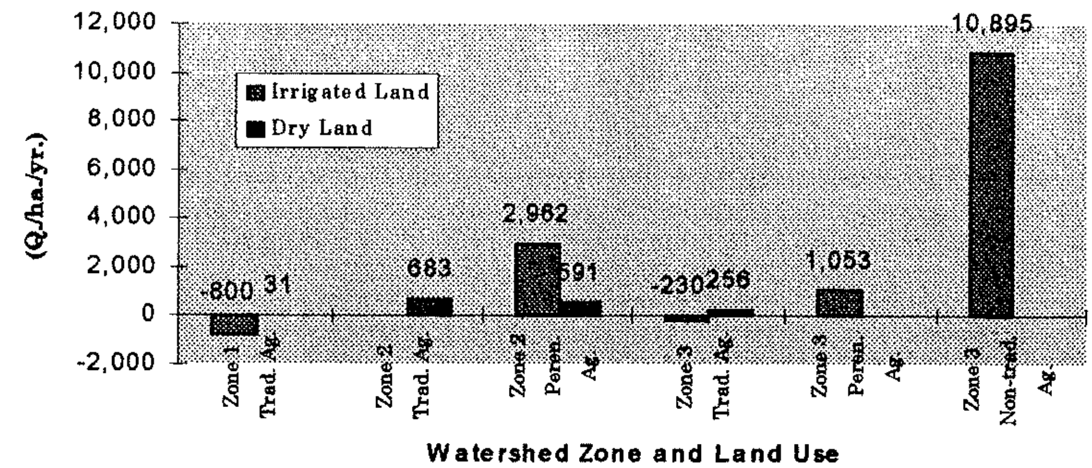
is almost 4 times as valuable as dry land, while in zones 2 and 3 it is 5.9 and 6.8 times as valuable. Irrigated land in zone 3 is far more valuable than in zones 1 and 2, because of topographic differences. In the middle and upper parts of this watershed, land is steep and rocky, whereas below the union of the Timiluya and Hato Rivers, the floodplain is wider and flatter.

Table 6.11 Hato Land Value (Quetzales/ha. and $/ha.)		
	Irrigated Land	*Dry or Rain-fed Land*
Zone 1	Q. 11,070 ($1,805.87)	Q. 2,850 ($464.93)
Zone 2	Q. 24,125 ($3,935.56)	Q. 4,070 ($663.95)
Zone 3	Q. 66,485 ($10,845.84)	Q. 9,770 ($1,593.80)

As Figure 6.12 indicates, irrigated land is substantially more productive than dry land in zones 2 and 3, on all land but that used for traditional agriculture. For example, in zone 3, up to Q. 10,895 per hectare can be earned annually on irrigated land, while dry land is used only for traditional agriculture, characterized by negative net profits. In zone 2, Q. 2,962 can be earned annually from a hectare of irrigated perennial fruit trees, which is approximately 5 times the profits of dry land crops.

As explained above for Jones, traditional agriculture often produces negative net annual profits, because this economic analysis includes the quantification of labor expenses that the farmers often do not actually pay, because they themselves or family members tend these subsistence crops. As shown in Table 6.12, gross earnings are always higher on irrigated land, but because more labor and inputs are dedicated to irrigated land, the result is more negative net profits.

Figure 6.12 Net Agricultural Profits, Hato Watershed



Extrapolating the annual net agricultural profit figures to cover the entire sampled area, which encompasses all of the Hato River but excludes the Timiluya river in the western portion of the watershed, one finds that the 279 ha. of irrigated land represent only <u>45.30%</u> of all land in production but produce <u>84.48%</u> of total profits. Irrigated land produces a total of Q. 575,111 ($93,819), while the 337 ha. of dry land produce only Q. 105,654 ($17,236). It is also clear from these figures that the Jones basin has more irrigated land (1,406 ha. versus 279 here) and is more profitable, because total agricultural profits in Jones were $906,974, while they were only $111,055 in the Hato watershed. Average profits per hectare of irrigated land are higher in Jones – $578.71 versus $336.57 in Hato – but a bit lower for dry land – $28.15 in comparison with $51.21 in Hato.

Table 6.12 Gross Agricultural Profits in the Hato Basin (Q./ha.)

	Irrigated Land	*Dry Land*
Zone 1 Traditional Ag.	1672 +/- 281	1349 +/- 246
Zone 2 Traditional Ag.	---	1,207 +/- 204
Zone 2 Perennial. Ag.	4,358 +/- 828	1,664 +/- 560
Zone 3 Traditional Ag.	2,489 +/- 372	429 +/- 196
Zone 3 Perennial Ag.	3,457 +/- 784	---
Zone 3 Non-traditional Ag.	21,434 +/- 7,568	---

In the Hato watershed, as in Jones, the availability of irrigation not only increases crop yields, but also allows the production of crops that could not be grown on dry land. The most profitable crops are the non-traditional fruits and vegetables such as melons, tomatoes, hot peppers and tobacco, grown in zone 3, that can only be cultivated on irrigated land. However, these crops require a much higher level of investment in fertilizers, pesticides, and quality seed, explains why only about 50 hectares (or 17%) of the irrigated land in zone 3 is dedicated to these crops.

For poor farmers, perennial crops represent an excellent investment, not only because they produce higher profits than traditional crops, but also because they require almost no inputs. In zone 2, for example, fruit trees produce average per-hectare gross profits of Q. 4,358 and net profits of Q. 2,962, meaning that production costs average Q. 1,396 per hectare, or the difference between gross and net profits. However, 99% of the production costs are labor expenses that the farmers do not actually pay, because they or their families tend the crops. Similarly, in zone 3, 96% of the production costs of fruit trees and sugar cane are labor expenses and only 4% are material inputs such as fertilizers and pesticides. In comparison, material inputs represent 48% of the production costs of non-traditional crops in zone 3, 25% of the production costs of traditional crops in zone 3 and 34% of the production costs of traditional crops in zone 1. Perennial crops such as fruit trees clearly represent the best option for poor farmers who have little money to invest in their crops.

As shown in Table 6.13, the farmers in zone 2 use five times more water per hectare than the farmers in zone 3. Located below the union of the Timiluya and Hato Rivers, these farmers have an abundant supply of water and appear to be using it very inefficiently. Water clearly has its highest productive value when used to irrigated non-traditional crops in zone 3, because these crops are the most profitable and because water is far more scarce here than in zone 2.

Table 6.13 Quantity of Irrigation (m3/ha./yr.) and Additional Productive Value Due to Irrigation

	Irrigation/Ha./Yr.	Additional Productive value/1000 m3 of irrigation
Zone 1 Traditional Ag.	9,730 +/- 3,737	-
Zone 2 Perennial Ag.	156,271 +/- 32,903	18.954
Zone 3 Traditional Ag.	35,078 +/- 9,278	-
Zone 3 Perennial Ag.	33,248 +/- 7,866	31.67
Zone 3 Non-traditional Ag.	37,088 +/- 16,338	293.76

In the Hato basin, several additional interviews were conducted to determine the productivity of small-scale agroindustry, particularly coffee and sugar mills. There are a total of 11 coffee mills and 9 sugar mills. The owners of 5 coffee mills and 4 sugar mills were interviewed. Average annual net profits per hectare for the coffee mills were Q. 11,333 +/- 1,930 and for the sugar mills were Q. 5,124 +/- 2,257, at the 75% confidence level. Although the small sample caused variation in profits to be rather high, these agroindustries clearly substantially increase the profits of these farmers. The per-hectare profits of the coffee mills are even higher than the profits of non-traditional crops, and the average sugar mill profits exceed all agricultural profits other than non-traditional crops.

6.3 RESULTS OF STATISTICAL ANALYSIS

Results from both Jones and Hato were combined for further analysis. First, the two watersheds were compared in terms of agricultural productivity, by calculating the benefit-cost ratio, and in terms of water productivity (agricultural productivity per unit of irrigation time). Second, regression analyses were conducted to identify what factors determine productivity per area and per hour of irrigation and to decide if differences in productivity between irrigated and dry land are statistically significant. Third, the models built through regression analyses were tested to determine how the quantity of irrigated land affects productivity per area, and to quantify the productive value of each additional hour of irrigation per hectare.

For part one of the analysis, agricultural benefit-cost and water productivity relationships calculated for each zone of each watershed are shown in Table 6.14. The benefit-cost ratio represents gross agricultural profits divided by all production costs, including materials and labor expenses. Water productivity represents gross agricultural productivity per hectare divided by the number of hours of irrigation.

In Jones, both benefit-cost and water productivity were highest in zone 2, while in Hato both were highest in zone 3. These areas each represent the zone with the highest water availability, because of the union of at least two rivers. In Jones, zone 2 begins just below where the Cañas, Colorado, Lima and Blanco Rivers unite to form the Jones River. In Hato, zone 3 begins just below the union of the Timiluya and Hato Rivers.

Table 6.14 Benefit-Cost Ratios and Water Productivity

Hato			*Jones*	
Water Prod. - Hato ($/Ha./Hr. Irrigated)	**B/C Hato**	**Zone**	**Water Prod. - Jones ($/Ha./Hr. Irrigated)**	**B/C Jones**
1.67	0.95	1	3.09	12.94
2.06	2.82	2	32.99	14.89
2.59	4.60	3	11.66	7.80

When comparing the two watersheds, it is clear that both the benefit-cost ratio and water productivity are consistently higher in Jones than in Hato, probably due to the predominance of cattle pasture, as well as the higher level of poverty in Hato. An analysis of variance (ANOVA) determined the differences between the watersheds to be statistically significant ($p<.001$) but did not find a statistically significant difference between the zones, on the aggregate, probably because the altitudinal limits of the zones were defined differently in the two watersheds.

The cost-benefit ratios correlated well with the water productivity levels. This suggests that the efficiency of water use has a strong effect on the relationship between agricultural benefits and costs. Or, it may be that the factors that affect agricultural productivity also affect water productivity.

For part two of the analysis, two multiple regression analyses were conducted to determine the effects of several variables on agricultural productivity and water productivity. The structure of the original regression formulae and the definitions of the variables are explained in chapter 4 and the results are provided in Table 6.15.

Table 6.15 Effect of Independent Variables on Agricultural Productivity and Water Productivity

	Agricultural Productivity		*Water Productivity*	
Variable	**Coefficient**	**Predicted Direction of Relationship (+/-)**	**Coefficient**	**Predicted Direction of Relationship (+/-)**
Hours	0.0503	+	--	–
Input	0.0498	+	0.9727	+
Labor	0.3119**	–	-4.8908**	–
Percent	0.0070**	+	0.1782**	+
Available	-0.0584	+	-0.0636	–
Awareness	0.0889	–	-2.4410	+
Crop	0.0269	+	0.1459	+
Size	0.1451**	+	3.6118**	+
Property	0.1923	+	-0.8747	+
Mixprop	-0.8050**	–	-4.7234	–
Zone	-0.0960	+	-5.5779	+
Basin	-0.2261	no prediction	1.9724	no prediction
Educ	0.0143	+	0.0668	+
Constant	3.6696**	no prediction	32.965**	no prediction

*** indicates significance at 95% confidence level (1-α=.05)*

The variables "labor," "percent," and "size" were found to be significantly correlated with both agricultural productivity and water productivity, and "mixprop" was found to be significantly correlated with agricultural productivity. So, the results indicate that agricultural productivity increases as labor expenses, property size and percentage of irrigated land increase and that productivity decreases under systems of joint land management. The positive correlation with labor expenses contradicted our prediction that greater labor efficiency (i.e., lower labor costs per hectare) would result in higher agricultural productivity. The significance of this correlation may reflect the value of more qualified labor in crop management. Also, some of the farmers we interviewed appeared to give little attention to their crops, which could cause disease and lower productivity. The other variables will not be discussed, because their effect on agricultural productivity was not statistically significant.

Similarly, water productivity was shown to increase as property size and percent irrigation increase and as labor expenses per hectare decrease. In this case, the directions of all of the correlations supported our predictions. None of the variables with correlations contrary to our predictions were statistically significant.

The strength of these regressions as prediction models was found to be low, with coefficients of determination (R^2) of 0.36 and 0.30, and many of the above variables were not found to be statistically significant. Therefore, the models were modified through a "stepwise" elimination procedure, in order to produce models that would be more useful for making predictions about the influence of various factors on the efficient and productive use of water for irrigation. The results are provided in Table 6.16.

Table 6.16 Results of Agricultural Productivity and Water Productivity Models After Stepwise Elimination Procedure

Variable	Coefficient	Predicted Direction of Relationship (+/-)	Coefficient	Predicted Direction of Relationship (+/-)
Hours	0.0576**	+	--	−
Input	0.0354	+	0.8919	+
Labor	0.3310**	−	-5.1357**	−
Percent	0.0057**	+	0.1801**	+
Size	0.1322**	+	3.2638**	+
Mixprop	-0.6488**	−	--	−
Zone	--	+	-4.4960**	+
$Rain^2$	0.0000018	+	--	+
Constant	2.8451**	no prediction	26.867**	no prediction

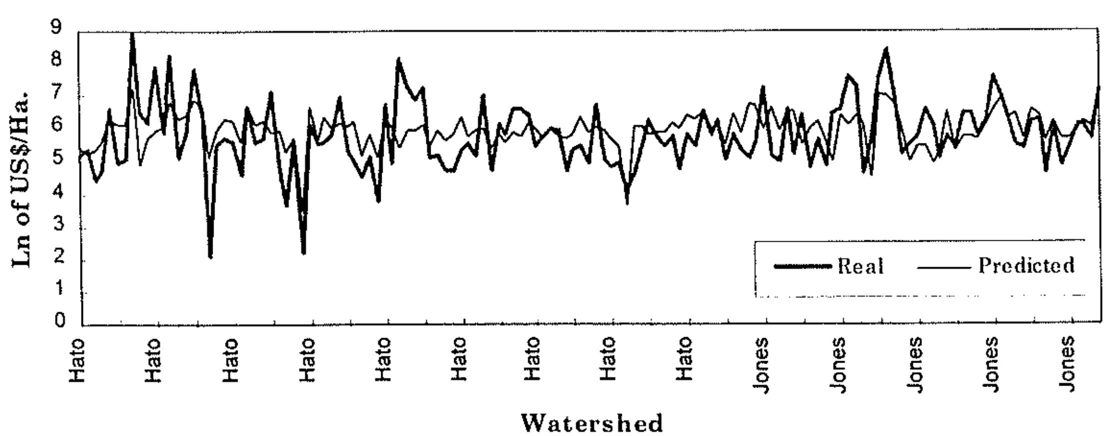
** *indicates significance at 95% confidence level (1-α=.05)*

After the stepwise elimination, labor expenses, property size, percentage of land irrigated and property management were still found to affect agricultural productivity at a statistically significant level, plus a positive correlation was found with the number of hours of irrigation. The directions of the correlations are the same as in the original model, with all but labor expenses supporting our predictions. The coefficient of determination decreased slightly, to 0.34, suggesting that important predictor variables are missing.

Similarly, in the case of water productivity, all of the variables originally found to be statistically significant (labor expenses, property size and percentage of land irrigated) remained significant, plus zone was found to be significant and agricultural inputs were very close to significant (p=0.0632). Water productivity was found to be negatively related to zone (contradicting our prediction), with higher agricultural productivity per hour of irrigation in the upper and middle than the lower basin in each watershed. This is probably because more water is available in these zones, so an hour of irrigation provided more water in the upper zones. Agricultural inputs were positively correlated with water productivity, as predicted. Once again, the coefficient of determination (R^2) was very low, 0.28, indicating that important determinant variables were missing.

In summary, both of the regression analyses identified similar determinant variables. In both cases, labor costs and percentage of irrigated land were significant. This demonstrates statistically that the value of water and its efficient use depend on the amount of labor invested and the quantity of land that can be irrigated. The statistical significance of "percent" indicated that there is a significant difference in productivity between irrigated and dry land, as is strongly suggested by the data presented earlier in this chapter. In addition, the results indicated that rainfall and the number of hours of irrigation are fundamental factors determining agricultural productivity. Finally, larger parcels of land are clearly more productive. Considering that the average parcel size for both watersheds combined was 1.12 hectares, we are clearly not talking about large areas.

Figure 6.13 Predicted and Real Values for Agricultural Productivity

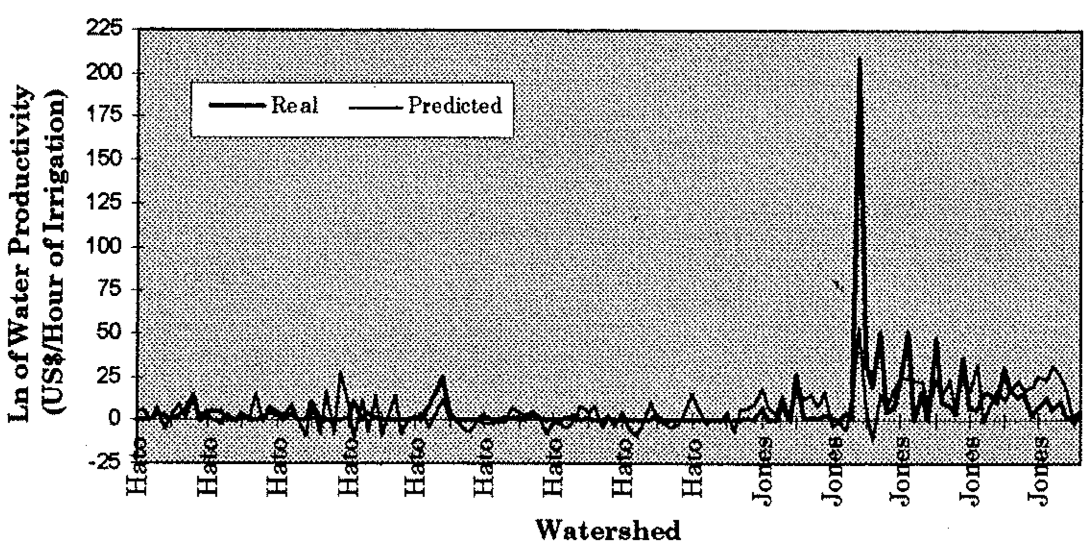


Finally, simulations were performed with the improved versions of both models, to compare predicted and real values of agricultural productivity per unit area and per hour of irrigation and to make predictions about potential changes in productivity that could result from changes in some of the independent variables. As can be seen in Figures 6.13 and 6.14, the level of prediction is acceptable, because the principal tendencies are accurately predicted.

The model was used to predict changes in productivity that could result from increasing average percentage of irrigated land from 70.39% to 100%, i.e. by increasing the average irrigated parcel size from 0.85 to 1.12 hectares. (It should be noted that parcel size is not equal to total land ownership, because most farmers own several parcels of land.) Currently, real annual per-hectare productivity (of all agricultural land, including irrigated and dry land together) is $334.44 and the model estimates current per-hectare productivity at $399.07, which is quite close to the real value. The model predicted that the increase in irrigated parcel size would increase agricultural productivity by $72.93 (Q. 447.05) per hectare.

productivity by $188.73 per hectare, from $399.07 to $587.79. This assumes that the rest of the variables remain the same. Sensitivity analyses and other tests must be performed on this model, to determine its robustness. Nevertheless, these preliminary results strongly indicate that agricultural productivity could be greatly enhanced through expansion of the irrigated area, which could possibly be attained through greater watershed protection and more efficient irrigation systems.

Figure 6.14 Predicted and Real Water Productivity Values



CHAPTER 7: SIMULATION OF HYDROLOGIC AND SOCIOECONOMIC EFFECTS OF DEFORESTATION

7.1 MODEL OVERVIEW

We modeled the change in land use and agricultural productivity that would result from changes in the river flow that is utilized for irrigation. The basic premise is that long-term changes in flow rates would result in a change in the area under cultivation, which would ultimately result in a change in the economic value of the crops produced on that land. The model was applied to the streamflow, irrigation flow, land use and economic data for the Jones and Hato watersheds that is described in Chapter 6.

As described in Chapter 6, each of the watersheds was divided into three altitudinal zones that differed in terms of land use patterns. In Jones, zone 1 is dominated by traditional agriculture, whereas zones 2 and 3 are devoted primarily to irrigated pasture. In Hato, by contrast, there is no irrigated pasture in any of the zones. Zone 1 is dominated by traditional agriculture, zone 2 is used entirely for perennial agriculture (fruit orchards), and Zone 3 has a mix of perennial, traditional and non-traditional agriculture.

Within each of the watersheds, we measured both river flow and irrigation flow for a representative subset of the channels flowing through the watershed. This represented the flow used in irrigating 46%, 76%, and 60% of the irrigated land in zones 1, 2, and 3 respectively in Jones, and 50%, 68%, and 61% of the irrigated land in Hato. River flow was repeatedly measured at a fixed location in each zone. The flow into the tomas irrigating the subset of each zone being studied was also repeatedly measured. These measures provide estimates of the sources and rates of water flowing into and out of each zone, and the amounts that were diverted for agricultural use.

The size of the area cultivated was used to estimate the economic value of agricultural production on irrigated land. Estimates of the value of land were made on a per-year and per-hectare basis for each crop type in each zone. These estimates were derived from data collected by interviewing local farmers. Although this data included productivity values for both irrigated and dry land, this model focused solely on the effect of changes in streamflow on irrigation profits.

7.2 MODEL ASSUMPTIONS

In order to generate a mathematical formulation of the agricultural system, we made the following simplifying assumptions:

1) The availability of water during the dry season is linearly related to the amount of land that is irrigated.

2) Decisions regarding the amount of land to be cultivated are made on an annual basis and accurately reflect the amount of land that can be productively irrigated.

3) Decisions regarding the amount of land to be cultivated are made on the basis of mean flow during the dry season.

4) Reductions in flow are long-term reductions and land use has equilibrated with the new flow levels.

5) Within each zone, there is a level of flow below which further flow cannot be diverted into the tomas.

6) The relative amounts of land in each agricultural category within a given zone do not change if the total amount of land in production within that zone changes.

7) The area that can be successfully irrigated is proportional to flow through the tomas, and the efficiency of this relationship does not change.

7.3 MATHEMATICAL FORMULATION

7.3.1 Variable Definitions

The following variables were used in the model:

j	Index for agricultural categories (1-4)
I	Index for time series of measurements of dry season flow rate in the main channel or in irrigation channels for zone k.
k	Index for zones (1-3)
Ru(i,k)	Flow rate in main channel above zone k at sampling time i.
Rt(i,k)	Flow rate in tomas below measurement of Ru(i,k).
ni(k)	Number of dry season measurements of Rt(i,k) and Ru(i,k).

S(k)	Proportion of irrigated area within zone k for which the inflow and irrigation flow were measured.
Rtmean(k)	Mean dry season irrigation flow into zone k measured in 1996.
Rumean(k)	Mean dry season flow into zone k above tomas, measured in 1996.
Fb(k)	Minimum (base) flow out of zone k after irrigation. This is the flow which cannot be diverted from the main channel, and consequently flows into the next zone downslope.
P(j,k)	The amount of land in production in agricultural category j in zone k. Based on 1996 values.
Ptot(k)	Total amount of land in production over all agricultural categories in zone j. Based on 1996 values.
d	Proportional reduction in flow resulting from deforestation or other long-term changes in the rate of flow. Proportion is expressed relative to 1996 dry season flow.
Pnew(k)	Perturbed amount of irrigated land in zone k. (i.e. d not equal to 1.0)
Runew(k)	Perturbed mean dry season flow into zone k above tomas.
Rtnew(k)	Perturbed mean dry season irrigation flow into zone k.
Q(j,k)	Value of agricultural production by zone and agricultural category in 1996 Quetzals per ha.
V(j,k)	Value of agricultural production by zone and agricultural category in 1996 Quetzals.

7.3.2 Model Structure

Figure 7.1 shows a general schematic of hydrologic flow into and out of each zone in these watersheds. The following formulae were used to calculate each of the major components of the model.

Mean flow into k for 1996, correcting for area of k sampled is:

Rtmean(k) = ((Sum [i=1,ni] Rt(i,k)) / ni) / S(k)

The mean irrigation flow in k for 1996, correcting for area of k sampled, is:

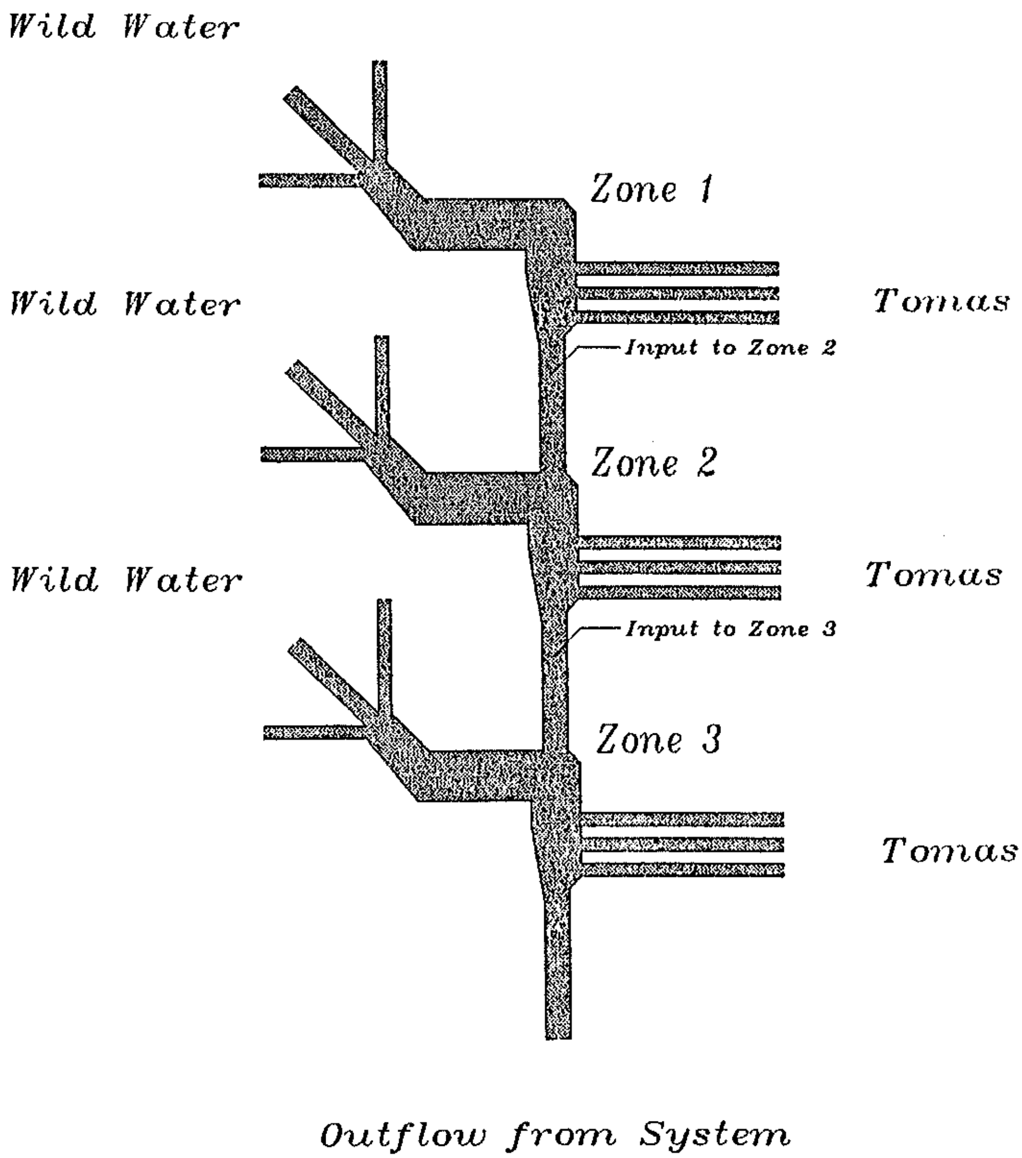
Rumean(k) = ((Sum [i=1,ni] Ru(i,k)) / ni) / S(k)

If the flow into k is perturbed due to deforestation or due to other factors, the input flow, Rumean, changes:

Runew(k) = d * Rumean(k)

Figure 7.1

Schematic of
Hydrologic Flow



Irrigation flow into zone 1 is simply the new flow into zone 1 less the amount that cannot be diverted into the tomas:

$$Rtnew(1) = Runew(1) - Fb(1)$$

Subject to the constraints that Rtnew(1) is greater than or equal to zero, and less than or equal to Rtmean(k).

Irrigation flow into zones downstream from Zone 1 (i.e. k greater than 1) are calculated iteratively:

$$Rtnew(k) = Runew(k) + Runew(k-1) -Rtnew(k-1) - Fb(k)$$

Subject to the same constraints. as for the computation of Rtnew(1). Computation of the area of zone k cultivated for a particular class of agriculture, Pnew(j,k), is based on assumptions 6 and 7 listed above:

$$Pnew(j,k) = (P(j,k)/Ptot(k)) * (Rtnew(k)/(Rtmean(k))$$

The value of Pnew(j,k) is the amount of land cultivated for agricultural type j in zone k given the change in water flow into the system specified by d. Economic value for each zone and agricultural type was computed using a zone and agricultural type specific valuation in 1996 Quetzals, Q(j,k) and then converted to 1996 U.S. dollars using a rate of Q 6.13 per dollar.

$$V(j,k) = [Pnew(j,k) * Q(j,k)]/6.13$$

7.4 INPUT VALUES

7.4.1 Jones Watershed

River and toma flow measurements were taken 11 times during January 5-April 26, 1996. These measurements were averaged to obtain dry season means which were used in all subsequent calculations. The dry season was defined on the basis of irrigation demand, which typically begins some time after the onset of the dry season in November. The area presently irrigated was assumed to be the maximum area irrigable, despite the availability in all zones of additional potentially irrigable land. This assumption was made because in zone 1 some potentially irrigable land was not irrigated, although sufficient water was available. Therefore it was assumed that there were other factors, such as topography, limiting the use of this land.

River flow and irrigation data were available for one of four streams in zone 1. Water from this stream provides for the irrigation needs of 46% of the irrigated land in Zone 1. The remaining three streams provide for the irrigation needs of the remaining 54% of the irrigated land. Water use patterns were extrapolated to the unmeasured area on the basis of area irrigated. All water entering Zone 1 is considered "wild water" as there is no irrigation above this zone. Of the 1,740 l/s available, 363 l/s were diverted into tomas. It was estimated that irrigation in this zone would begin to be affected at 85% of present river flow levels, because most of the irrigated land is concentrated along only one of the four streams. At flow rates of 1,133 l/s or below, no water would be available for irrigation because access to this water is beyond the capabilities of the present irrigation system. This relatively high non-usable flow is due to the small amount of land suitable for irrigation adjacent to all three of the unmeasured streams.

River flow and irrigation data were available for the upstream portion of zone 2, representing 76% of the area irrigated in this zone. The remaining 24% of the irrigated land uses water drawn from tomas downstream of the measured area. Of the 1,397 l/s presently available for use in zone 2, 1,278 l/s is diverted into tomas. This estimate includes both the measured tomas and an amount extrapolated for the remaining downstream tomas. Only 119 l/s remains as a source of water to Zone 3. This is considered to be the non-usable flow; Zone 2 is at water capacity. Any reductions in water available would be reflected immediately in area irrigated.

Table 7.1 Summary of Input Values for Jones Watershed

Variable		Zone 1	Zone 2	Zone 3
Measured	Rumean	236	0	570
	Rtmean	167	971	299
	Fb	34	---	---
Estimated	Rumean	1524	---	---
	Rtmean	196	307	199
	Fb	1099	119	191

As in zone 2, river flow and irrigation data were available for the upstream portion of zone 3. This represents 60% of the area irrigated in this zone; the remaining 40% of the irrigated land uses water drawn from tomas downstream of the measured area. In addition to the 119 l/s received from zone 2, 570 l/s of "wild water" is added to zone 3 from at least one additional stream. Of the total 689 l/s presently available to zone 3, 498 l/s is diverted into tomas. Approximately 191 l/s flows out of zone 3; this is also non-usable flow. Zone 3 is at water capacity, and any reductions in water available would be reflected immediately in area irrigated.

7.4.2 Hato Watershed

River flow measurements and toma flow measurements were taken 11 times during February 13-April 30, 1996. These measurements were averaged to obtain dry season means which were used in all subsequent calculations. The dry season was defined on the basis of irrigation demand, which typically begins some time after the onset of the dry season in November. The area presently irrigated was assumed to be the maximum area irrigable.

Zone 1 of Hato was similar to zone 1 of Jones in that river flow and irrigation flow were measured on one stream and water use was extrapolated to the remaining irrigated area along another stream. Of the 482 l/s available for use in this zone, 44.6 l/s were diverted into tomas. It was estimated that irrigation in this zone would begin to be affected at 50% of present river flow levels. At flow rates of 196.4 l/s or below, no water would be available for irrigation because access to this water (much of which runs between and under boulders) is beyond the capabilities of the present irrigation system.

River flow and irrigation data were available for the downstream portion of zone 2, representing 68% of the area irrigated in this zone. The remaining 32% of the irrigated land uses water drawn from tomas upstream of the measured area. Of the 711 l/s presently available for use in zone 2, 506 l/s is diverted into tomas. This estimate includes both the measured tomas and an amount extrapolated for the remaining upstream tomas. Only 205 l/s remains as a source of water to zone 3. This is considered to be the non-usable flow. In other words, zone 2 is assumed to be at water capacity. Any reductions in water available would be reflected immediately in area irrigated.

Table 7.2 Summary of Input Values for Hato Watershed

Variable		Zone 1	Zone 2	Zone 3
Measured	Rumean	241	274	1018
	Rtmean	22.3	344	547
	Fb	98.2	---	---
Estimated	Rumean	241	---	---
	Rtmean	22.3	162	350
	Fb	98.2	205	82

River flow and irrigation data were available for the upstream portion of zone 3. This represents 61% of the area irrigated in this zone; the remaining 39% of the irrigated land uses water drawn from tomas downstream of the measured area. In addition to the 205 l/s received from zone 2, 1,018 l/s of additional water is added to zone 3 from the Timiluya River. Because this flow is also subject to irrigation use, the amount of flow available from the Timiluya is calculated at each level of river flow based on the estimated irrigation demand. Of the total

1,223 l/s presently available to zone 3, 897 l/s is diverted into tomas. Approximately 326 l/s flows out of zone 3. Zone 3 is estimated to be below water capacity; area irrigated would be affected beginning at 80% of present river flow.

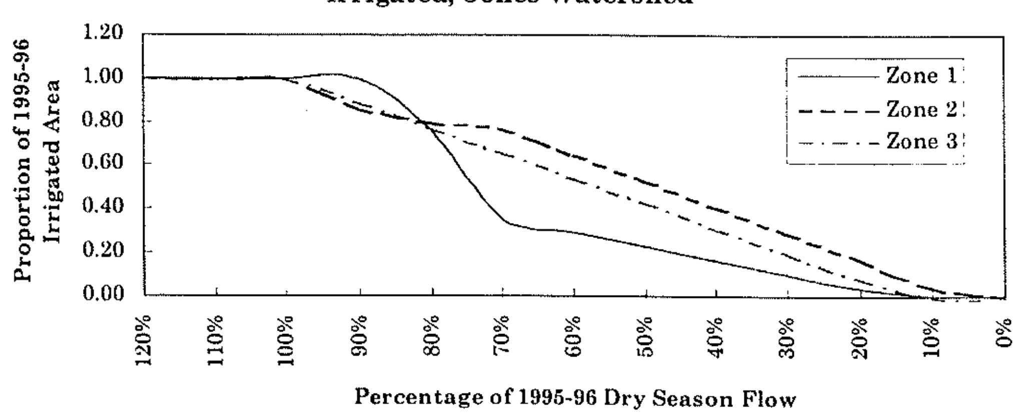
7.5 SIMULATION RESULTS

7.5.1 Dry Season Flow, Area Irrigated and Income

7.5.1.1 Jones watershed

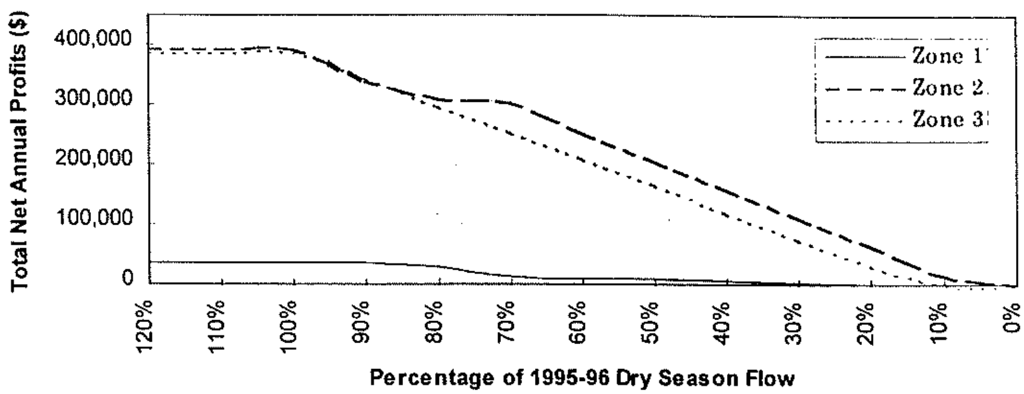
In the Jones watershed, zone 1 farmers would not be affected by reductions in dry season flow until river flow was reduced to 85% of present flow. Area irrigated would decline rapidly thereafter; as shown in Figure 7.2, at 70% of present river flow, zone 1 could only sustain half the irrigated area now in production. This is because the farmers in zone 1 draw irrigation water from smaller sources than those in zones 2 and 3 – each farmer cultivates land along one of four rivers that unite at the top of zone 2 to form the Jones River; although there is currently some excess water that they are not utilizing, once dry season flow drops below 85% of present flow, the effect of water scarcity will be felt most severely along these smaller rivers. This situation is aggravated by the fact that more than half of the irrigable land is located along only one of these four rivers.

Figure 7.2 Effect of Change in Dry Season Flow on Area Irrigated, Jones Watershed



Zones 2 and 3 would be affected immediately by a decrease in dry season flow, because both of these areas are currently at water capacity. As discussed in Chapter 6, irrigation in zones 2 and 3 frequently represents 80-90% of river flow during the dry season, so if streamflow were to drop to 70% of current flow, approximately 20% of the irrigated land in zone 2 and 30% of the irrigated land in zone 3 would have to be taken out of production or converted to dry agricultural land. Zone 3 would be affected more severely, because less water is available for irrigation in this zone, because it is affected by upstream use. The amount of land irrigated would not increase if more water were available, because topography or perhaps other factors appear to limit the area that can be irrigated by this gravitational system.

Figure 7.3 Economic Effect of Changes in Dry Season Flow, Jones Watershed



Zones 2 and 3 have a much larger amount of irrigated land than zone 1, and this land generates higher net profits. Therefore, these areas would experience the greatest absolute economic losses after decreases in dry season flow, as shown in Figure 7.3. If dry season flow were to decrease by 20%, annual net profits generated by irrigated land in zone 2 would fall from $392,683 to $311,607 (a 21% decrease), while in zone 3 they would decrease 23%, from $386,440 to $297,975 and in zone 1 they would fall 24%, from $37,849 to $28,670. While the proportional loss of profits is similar in all zones, clearly the absolute losses would be greatest in zones 2 and 3. However, one could also argue that because zone 1 is the poorest area, each dollar lost here would take the greatest toll on overall family income, probably further aggravating the vicious cycle of poverty, deforestation and watershed degradation. The deforestation that occurs in the upper basin is fueled by the poverty and need for more agricultural land of the residents of this zone.

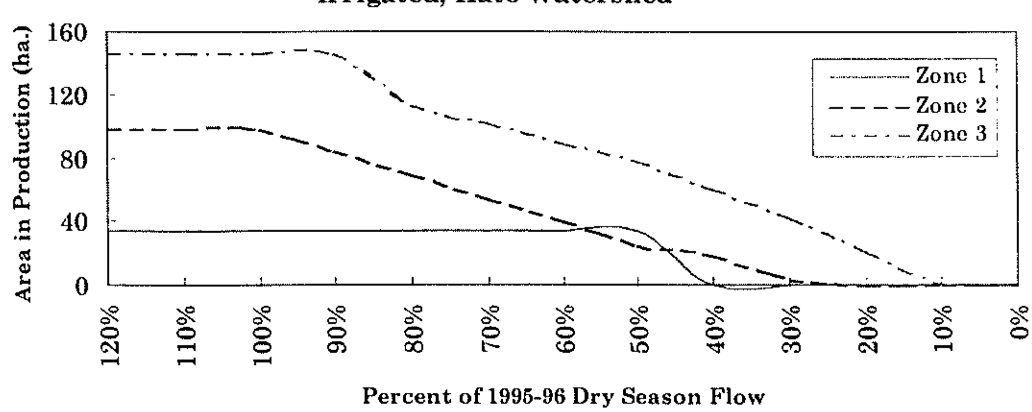
7.5.1.2 Hato watershed

In zone 1 of the Hato watershed, because water supply greatly exceeds demand, farmers would not be affected by reductions in dry season flow until river flow was reduced to 50% of present flow. However, because no water is available for irrigation below flow rates of 196.4 l/s, the amount of land irrigated would fall abruptly from 33.9 to 0 ha. if dry season flow were to fall below 50% of current flow.

Reductions in dry season flow would have an immediate impact in zone 2, where farmers are currently operating at water capacity. In zone 3, where water is much more abundant than in zone 2, irrigation would begin to be affected at 80% of current flow. However, it is important to keep in mind that streamflow in zone 3 is affected by upstream water use along both the Hato and Timiluya Rivers; because farmers upstream would continue to divert as much water as they could from a decreasing supply, a 20% decrease in streamflow upstream would result in more than a 20% decrease in the flow that reaches zone 3.

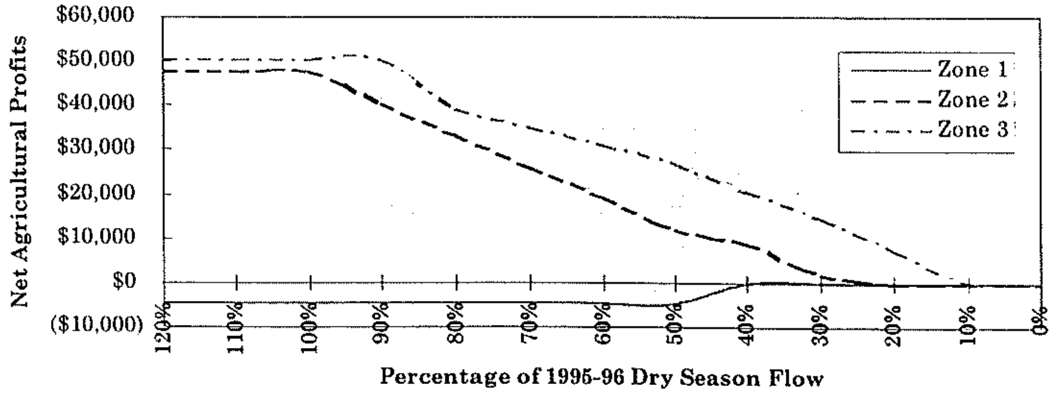
As shown in Figure 7.4, if streamflow were to decrease, the amount of land irrigated would decrease more steadily and gradually in zones 2 and 3 than in zone 1, and zone 2 would experience a greater proportional loss of irrigated land than zone 3. With a 20% decrease, the amount of irrigated land would decrease 30% in zone 2, from 98.5 to 69.1 ha. and 23% in zone 3, from 146.41 to 113.20 ha..

Figure 7.4 Effect of Change in Dry Season Flow on Area Irrigated, Hato Watershed



Reductions in streamflow would cause the greatest absolute and relative economic losses in zone 2, because land is more profitable in this area (as discussed in Chapter 6). As shown in Figure 7.5, if dry season flow were to decrease by 30%, annual net agricultural profits from irrigated land in zone 2 would decrease by 45%, from $47,595 to $26,286, while in zone 3 they would decrease by 31%, from $50,654 to $35,207. Even a decrease of 10% in dry season flow would cause a loss of over $7,000 in zone 2. Meanwhile, because irrigated land is used almost entirely for traditional annual crops in zone 1, all net profits are negative.

Figure 7.5 Economic Effects of Changes in Dry Season Flow, Hato Watershed



7.5.2 Deforestation, Dry Season Flow, Area Irrigated, and Income

7.5.2.1 Jones watershed

Using the results of the paired basin studies, it was possible to estimate the effect of deforestation on dry season flow and therefore to project changes in area irrigated and net annual income. The Honduran pair of basins was utilized for this analysis, because more data was available from this pair than from the Guatemalan pair. The Honduran pair also represents the more conservative of the two pairs of basins – in Honduras, dry season flow in the deforested basin represents 47.63% of the flow of the forested basin, whereas in Guatemala it was 30.93%.

Using the ratio of mean dry season flow in the completely deforested and completely forested basins, a table was constructed describing the reduction in dry season flow expected at various levels of deforestation. In the absence of detailed studies of this relationship, reduction in water flow was assumed to be directly proportional to percent deforestation. As discussed in Chapter 5, much of the reduction in dry season flow after deforestation is believed to result from soil degradation and loss of infiltration capacity rather than from the deforestation itself. However, because soil conservation is rare in the SMBR, it is assumed that deforestation would be accompanied by similar soil degradation.

In the Jones watershed, a light level of further deforestation would affect zones 2 and 3 more severely than zone 1, in terms of the proportion of irrigated land that would be lost, because these areas are currently at water capacity. However, if 40% or more of remaining forest cover were removed, zone 1 would be most severely affected; as shown in Figure 7.6, at 50% deforestation, zone 1 would lose 43% of its irrigated land, while zones 2 and 3 would lose 15% and 23%, respectively. Under severe deforestation, zone 2 appears to be the most resilient area, because of the relative abundance of water in this area.

Figure 7.6 Effect of Deforestation on Area Irrigated, Jones

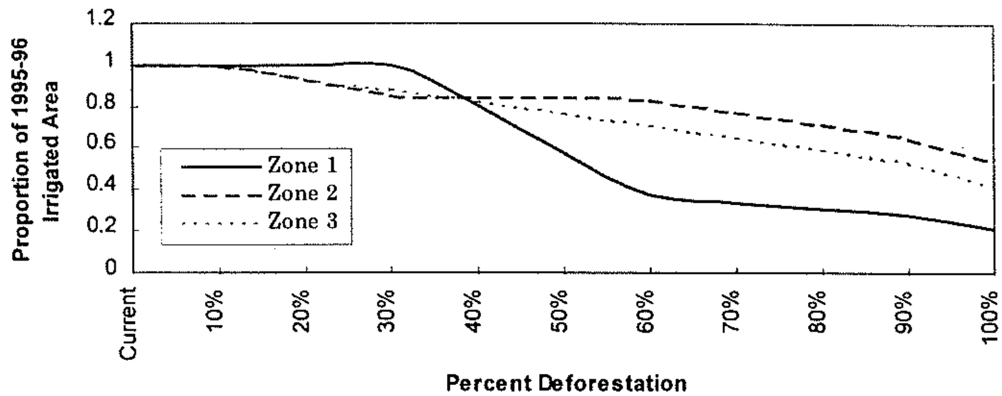
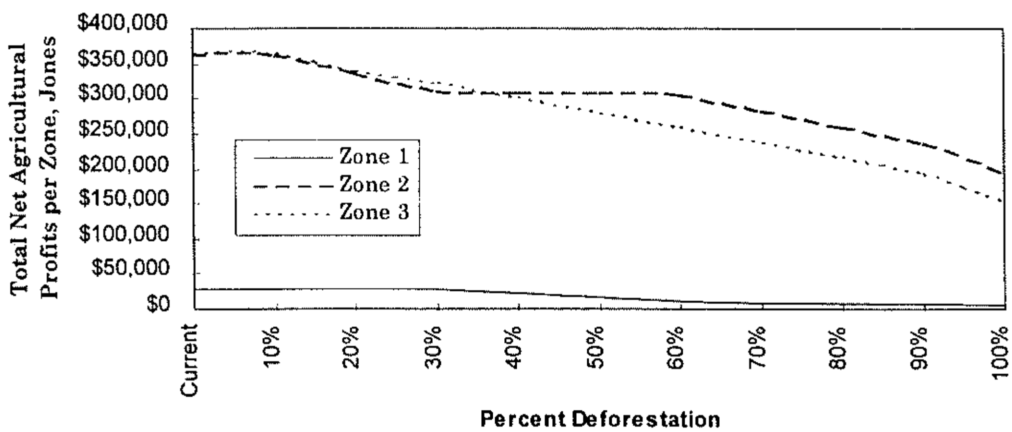


Figure 7.7 Projected Economic Effects of Deforestation, Jones

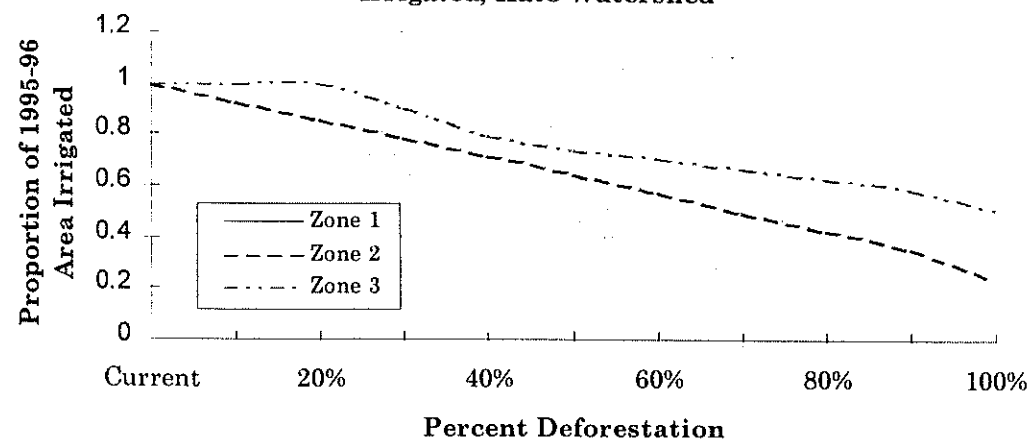


Because land is fairly profitable in this watershed, economic losses would be high, even under moderate deforestation. If 20% of current forest cover were cut, 9% of annual net profits would be lost in both zones 2 and 3, representing a total loss of approximately $26,000 in each zone, as shown in Figure 7.7. Forty percent deforestation would cause the total amount of land irrigated in the watershed to decrease 15-19% (varying only slightly between zones), causing annual profits to decrease by $123,712.

7.5.2.2 Hato watershed

In the Hato watershed, only very severe deforestation would cause a decrease in the area irrigated in zone 1 (see Figure 7.8). Because of the relative abundance of water, zone 3 would be affected by decreases in dry season flow only after deforestation exceeded 20%. The most sensitive area is clearly zone 2, where loss of one-fifth of current forest cover would cause a 14% decrease in irrigated area and loss of half of the remaining forest would lead to a 36% decrease in irrigated area.

Figure 7.8 Effect of Deforestation on Proportion of Area Irrigated, Hato Watershed

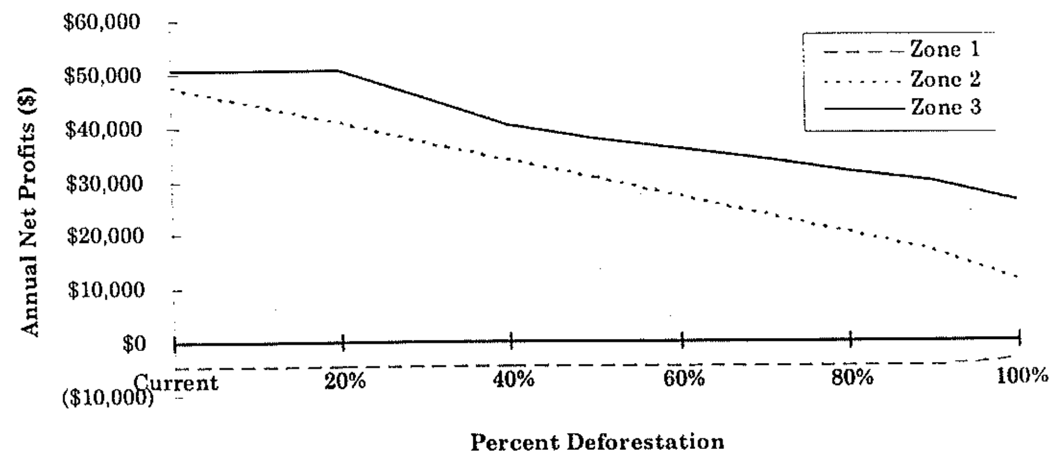


Projected changes in agricultural profits show consistently negative net profits in zone 1, as shown in Figure 7.9, because only annual traditional crops were sufficiently abundant to be included as irrigated crops. Coffee, a common and far more profitable crop in the upper watershed, is only irrigated briefly when young and is generally considered a dry-land crop. The high humidity and heavier rainfall in this area allow the cultivation of crops such as coffee and cardamon on dry land.

Zone 3 would be more resilient to further deforestation than zone 2, because of the relative abundance of water. For example, if 30% of the remaining forest were to be cut, agricultural profits would decrease by 10% in zone 3, from

$50,647 to $45,635, whereas in zone 2 they would decrease by 21%, from $47,595 to $37,448. Even a loss of 20% of remaining forest cover would cost almost $7,000 (14% of current profits) in zone 2. It is important to point out that zone 2, which includes the towns of Chanrayo and El Cimiento, is an impoverished area, where families own an average of 0.66 hectares of irrigated land and 1.27 of dry land, so this loss of income would have a strong impact.

Figure 7.9 Economic Effect of Deforestation, Hato Watershed



Clearly, agricultural profits from irrigated land are higher in the Jones watershed than in Hato. Because of this, potential economic losses due to deforestation are far higher. For example, a 20% loss of remaining forest cover would cause a total loss of approximately $52,000 in Jones, whereas economic losses in Hato are estimated at $6,765. However, because Jones currently retains a higher proportion of remaining forest cover, 20% deforestation is less likely and would require cutting a much larger area.

If one of the goals of protected area management is the alleviation of poverty that drives the vicious cycle of resource degradation and deepening poverty, these results suggest that watershed management attention should be focused in the poorer areas, such as zone 1 of both watersheds and the middle and lower Hato basin, where agricultural profits that sustain many poor families appear particularly vulnerable in this already degraded basin.

7.6 EFFECTS OF MODEL ASSUMPTIONS

The results of the model depend strongly on the assumptions made and the data available. A strong effort has been made to make realistic assumptions, based on information gathered through field visits and general knowledge of the sites. For example, the linear relationship assumed to exist between irrigation flow and irrigable area is based on knowledge of this gravitational system, in which water is diverted from the channel onto each farmer's land during his or her irrigation time. It seems reasonable that less water in the channel would mean that flow would not reach the bottom of each irrigated parcel, unless irrigation time were increased, at the expense of another farmer's irrigation time.

However, it is clear that this simple rustic system is very inefficient and wasteful -- for example, farmers in zone 1 of Jones use at least twice as much water to irrigate a hectare of pasture as those in zone 3, and in Hato farmers in zone 2 use 5 times as much water per hectare to irrigate perennial fruit orchards as those in zone 3, although less water is available in zone 2. Therefore, it appears that some reductions in dry season flow could be managed through improvements in efficiency of water use. However, because it is unlikely that these changes will occur unless farmers become better organized on the watershed level, it was assumed that the efficiency of water use would not change.

Similarly, assumptions were made concerning the level of reduction in dry season flow that could occur before an area (such as zone 1 in both basins) is considered water-limited and the level of flow below which no more water could be removed from the stream using these simple channels (and hoses at the top of Hato). If any of these assumptions appear unrealistic, they should be changed and the model should be run again.

Clearly, the model also depends strongly on the data available to explain each component. Streamflow varies from year to year, and the 1995-96 dry season was wetter than usual, with rains beginning in mid-April rather than mid-May, so water scarcity may be more critical than observed.

The weakest link in the model is probably the paired basin data. The effect of deforestation on dry season flow is very site-specific and depends heavily on topography, rainfall patterns, soil depth and texture, and how land is used after deforestation occurs. This relationship has been studied very little in degraded tropical watersheds, although seasonal water scarcity appears to be a very common problem in the tropics. More research is clearly needed in this area.

CHAPTER 8: SOCIOECONOMIC ANALYSIS OF WATER USE FOR HYDROPOWER, INDUSTRIAL PRODUCTION AND DOMESTIC SUPPLY

Although water is used primarily for irrigation in the Motagua Valley, it has also influenced the development of the region in other ways. Several industrial companies have been located in the Valley in order to take advantage of the abundant, high quality water resources. Some families in isolated locations in the upper watersheds are provided electricity through small-scale hydropower development. And of course numerous rural families receive domestic water supply from the rivers in the area. The following three short analyses examine the socioeconomic value of water for these uses.

8.1 SMALL-SCALE HYDROPOWER IN THE HATO WATERSHED

In the upper east portion of the Hato watershed, in the towns of Los Albores and El Carmen, there are eleven pelton wheels used to generate electricity for local families and to generate mechanical power used to process coffee. These generators provide domestic electricity for 41 families (215 people), who use an average of 9 hours of electricity daily (primarily in the evening), throughout the year. The generators have been in use for an average of 13.5 years.

Interviews were conducted with all pelton wheel owners in September 1995, to estimate the economic value of the hydroelectricity generated by several streams in the Hato basin. During this month, 175,719 watts of electricity were generated and utilized per day, of which 52% were used for lighting and 48% for electrical appliances, primarily televisions. Calculations are shown in Table 8.1. This represents an annual consumption of 64,137 kilowatts, the market value of which, at Q. 0.50 per kilowatt (INDE 1996), would be Q. 32,069 or about $5,231 or $128 per family.

Another economic benefit obtained from the pelton wheels is the generation of mechanical energy used to process coffee; 78% of the pelton wheels are utilized to move the machines that depulp and dry the coffee. The value of this mechanical energy is high if one considers that the alternative is to use diesel motors, which are expensive to operate and maintain. During the 1993-94 agricultural year, a total of 3,252,000 pounds of mature coffee fruit was processed and 498,000 pounds of beans were dried.

Finally, it is necessary to emphasize the value of locally-generated electricity to the communities at the top of the Hato basin. Incorporating these communities into the national electrical grid would be prohibitively expensive, due to the distance of these communities from the grid and the low level of investment made by the government in rural areas such as this. Located approximately 27 km. from San Agustin de Acasaguastlan, the investment required to connect these communities would include Q. 20.25 million ($3.375 million) for the principal line and a cost to each family of Q. 3,000 ($500) for the secondary line needed to connect each family.

Table 8.1 Estimated Consumption of Hydroelectric Power, Upper Hato Watershed				
Light Bulb or Appliance	Estimated Consumption (watts/hr)	Number Used	Average Use (hrs/day)	Estimated Consumption (watts/day)
Light Bulbs				
Bulb 25W	25	92	5.58	12834
Bulb 40W	40	9	3.6	1296
Bulb 50W	50	33	8.5	14025
Bulb 60W	60	66	8	31680
Bulb 75W	75	16	5	6000
Bulb 100W	100	27	7.25	19575
Incandescent bulb 20 W	20	40	3.8	3040
Incandescent bulb 25 W	25	10	6	1500
Incandescent bulb 40 W	40	3	7	840
			SUBTOTAL	90,790
Electric Appliances				
Radios	50	26	3	3900
Televisions	600	29	4.2	73080
Musical equipment	400	10	0.74	2960
Iron	1000	3	0.42	1260
Blender	45	4	0.05	9
Refrigerator	150	1	24	3600
Battery charger	40	2	1.5	120
			SUBTOTAL	84,929
			TOTAL	175,719

8.2 INDUSTRIAL WATER USE

A total of 37 companies are located between the Sierra de las Minas and the Motagua River, as shown in Figure 8.1. An inventory conducted in 1994 identified 9 forest product companies, 17 agricultural product companies, 5 mining companies, 3 bottling companies, 2 energy suppliers, and 1 paper producer, as shown in Table 8.2. These companies are located in the Motagua Valley because of the accessibility of raw materials such as wood, marble, agricultural products, and high-quality drinking water and the transportation infrastructure in this zone, especially the Atlantic highway.

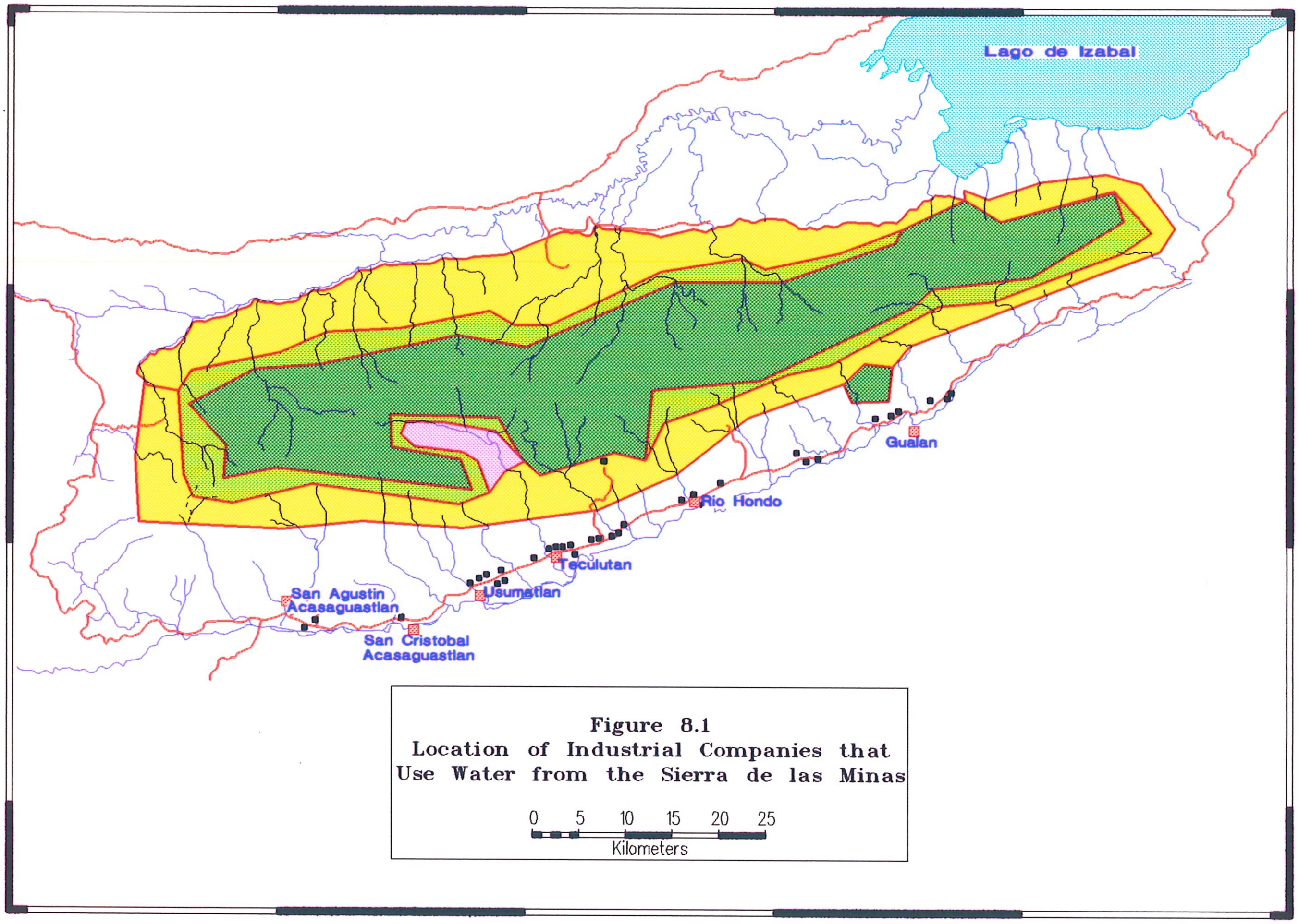


Figure 8.1
Location of Industrial Companies that Use Water from the Sierra de las Minas

Table 8.2 Industries Located In The Motagua Valley		
No.	COMPANY NAME	LOCATION AND DISTANCE FROM THE CAPITAL
Forest Product Industry		
1.	Inpregnadores de Maderas de Guatemala S.A.	Gualán Zacapa, 167 Km.
2.	Expola S.A.	Gualán Zacapa, 163 Km.
3.	Aserradero El Porvenir	Gualán Zacapa, 163 Km.
4.	Maderas Quiché	Rio Hondo Zacapa, 124 Km.
5.	Procesadores de Maderas Tropicales S.A.	Uzumatlan Zacapa, 112 Km.
6.	Maderas El Alto S.A.	Uzumatlan Zacapa, 110 Km.
7.	Maderas Semi Elaboradas de Guatemala S.A.	Uzumatlan Zacapa, 110 Km.
8.	Molmarce S.A.	San Agustin Aca. El Progreso, 85 Km.
9.	Industria de Maderas para Exportacion S.A.	San Agustin Aca. El Progreso, 85 Km.
10.	Papelera Internacional S.A.	Rio Hondo Zacapa, 125 Km.
Industrias de Productos Agricolas		
11.	Grupo pre-cooperativa El Rosario	Rio Hondo Zacapa, 152 Km.
12.	Cooperativa El Rosario	Rio Hondo Zacapa, 151 Km
13.	Coop. Agrícola Regional de Productos Varios R.L.	Teculután Zacapa, 121 Km.
14.	Tabacos Maya	Rio Hondo Zacapa, 128 Km
15.	Alimentos Congelados S.A.	Rio Hondo Zacapa, 125 Km
16.	Beneficio de Café La Unión	Gualán Zacapa, 164 Km.
17.	Tostaduría de Café, Beneficio de Arroz "Orquidea"	Gualán Zacapa, 164 Km.
18.	Difratti Río Hondo	Rio Hondo Zacapa, 123 Km
19.	Difratti San Cristobal	San Cristobal Aca. El Progreso, 100 Km.
20.	Vimosa	Uzumatlán Zacapa, 111 Km.
21.	Dulce Luís Orrellan	Rio Hondo Zacapa, 140 Km
22.	Finca "Las Pilas"	Teculután Zacapa, 121 Km.
23.	Finca "Santa Rita"	Uzumatlan Zacapa, 117 Km.
24.	Finca "El Zapotillo"	Teculután Zacapa, 121 Km.
25.	Finca "La Floresta"	Uzumatlán Zacapa, 112 Km.
26.	Finca "La Nueva"	Uzumatlán Zacapa, 114 Km.
27.	Unidad de Riego La Palma	Rio Hondo Zacapa, 152 Km
Mining Companies		
28.	Fertilaza - Ferquigua	Rio Hondo Zacapa, 122 Km.
29.	Mármoles Merendon S.A.	Gualán Zacapa, 156 Km.
30.	La Ceiba S.A.	Rio Hondo Zacapa, 125 Km.
31.	Tejera Las Joyas	Rio Hondo Zacapa, 135 Km.
32.	Marmoles de Guatemala S.A.	Teculutan Zacapa, Fca. San Lorenzo
Bottling Companies		
33.	Enbotelladora El Atlántico (Pepsi Cola)	Teculután Zacapa, 122 Km.
34.	Distribuidora del Atlantico (Coca Cola)	Rio Hondo Zacapa, 126 Km.
35.	Licorera Zacapaneca S.A.	Rio Hondo Zacapa, 127 Km.
Power Companies		
36.	Instituto Nacional de Electrificación	Rio Hondo Zacapa, 136 Km.
37.	Gas Metropolitano	San Agustín Aca. El Progreso, 85 Km.

Based on the inventory, eight companies were chosen for detailed interviews, to obtain information about the quantity and quality of water used and issues

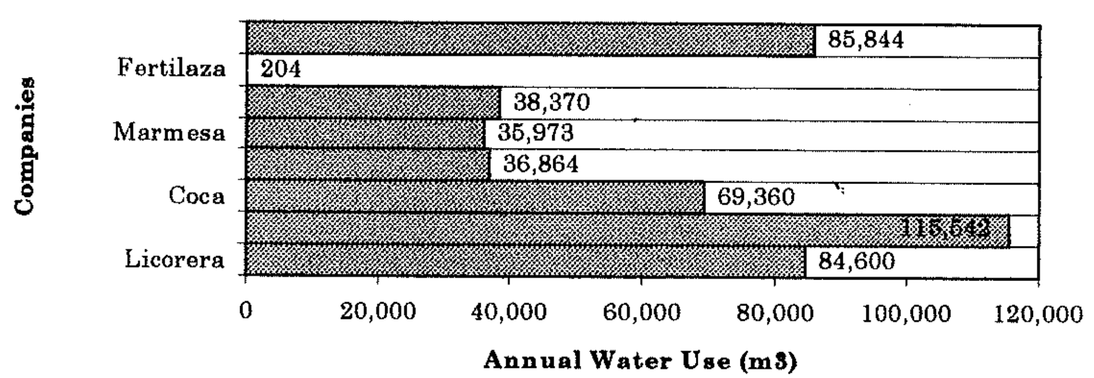
Based on the inventory, eight companies were chosen for detailed interviews, to obtain information about the quantity and quality of water used and issues related to water use. Each of these companies is considered to use a substantial amount of water in their production processes:

1. Embotelladora del Atlantico (Pepsi Cola Bottling Co.)
2. Distribuidora del Atlantico (Coca Cola Bottling Co.)
3. Licorera Zacapaneca S.A. (Zacapa Liquor Co.)
4. Papelera Internacional or Painsa (International Paper)
5. Ferquiqua - Fertilaza (fertilizer)
6. Alimentos Congelados S.A. or Alcosa (frozen foods)
7. Marmoles Merendon S.A. or Marmesa (marble mining)
8. Marmoles de Guatemala or Guatemarmol (marble mining)

The use of water in the Valley is clearly not regulated. Almost two-thirds of the industry representatives said that they never requested permission to extract water, while the other 37% couldn't remember from whom they had requested permission. None of the companies pay for the water they use and the quantity used is not limited or regulated in any way.

Figure 8.2 shows that the bottling companies use the most water -- the greatest consumer being Pepsi, which uses 115,542 m3 annually -- which is logical, since water represents the principal input in the production of soft drinks and liquor. In addition, the frozen foods company (Alcosa) uses a large quantity of water, especially to wash the foods they process.

Figure 8.2 Industrial Consumption of Water from the Sierra de las Minas



Seventy percent of this water is groundwater and 30% surface water. Six of the companies use only groundwater, one uses only surface water and one obtains half of its water from each source. None of the representatives have encountered problems due to scarcity of groundwater and none of the companies have had to deepen their wells. However, those that use surface water do experience seasonal scarcity. Four of the companies that consume the most water (Coca Cola, Licorera Zacapaneca, Painsa and Alcosa) said that their production is limited by water scarcity between February and April.

In terms of water quality, several of the companies mentioned problems with water hardness, which suggest high levels of salts such as carbonates and bicarbonates. Many of the companies treat the water before using it.

Very little wastewater is treated by these companies. Principal wastes include caustic salts from the bottling companies, chemical fertilizer wastes, bleaches and other toxic chemicals used in the production of paper, and dissolved marble. Most of the companies dispose of these wastes in nearby rivers that flow into the Motagua River, except for one that uses a settling pond. The paper company, which produces fiber waste and chemical dyes, uses a settling pond and paper filter before disposing of the wastes in the Pasabien River. An evaluation should be conducted of all wastewater and the effectiveness of current water treatment methods.

It was not possible to estimate the socioeconomic value of this industrial water, because most of the companies were unwilling to provide the necessary information. However, data from one of the bottling companies indicated that in 1994 production costs represented 26% of gross profits, which indicates a very high profit margin obtained from the high quality water resources of this region. We believe that it would be just to designate some of these funds to protection of the watersheds that provide this water.

Based on the above information, we conclude that industrial water use is disorganized and completely unregulated, both in terms of the quantity of water extracted from aquifers and rivers and in terms of the lack of wastewater management. Almost two-third of the companies indicated that over the next 5 years their companies plan to increase production. Although there are no signs of scarcity of groundwater, increased water use will aggravate scarcity and conflicts over surface water and increase the downstream impacts of water pollution.

8.3 DOMESTIC WATER SUPPLY SURVEY

A survey was conducted to determine the socioeconomic value of domestic water supply and explore the problems and costs related to shortages in water supply on the southern side of the Sierra. In the Jones watershed, 143 female heads of households were interviewed in 13 towns, representing approximately 16% of the sample population. The average age of the women was 42, 88% were married, and most have between 3 and 4 children. Most of the women have received very little education. Twenty-three percent never went to school, 40% attended school through 3rd grade, and 33% finished sixth grade.

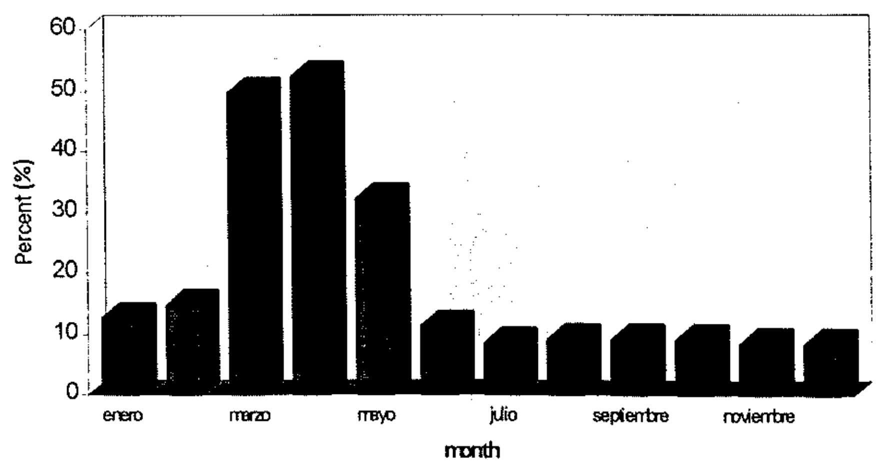
Most of the homes in the watershed reflect a decent but modest standard of living. Over half are made of cement, 47% are at least partially made of *bajareque* (a structure of logs filled with dirt and sealed with local plaster), and only 10% are made of adobe, the cheapest material available. Over 90% of the houses have electricity and over 60% have gas stoves. Nevertheless, for cultural as well as economic reasons, three quarters of the women cook with wood stoves, using firewood that they gather from pastures and forests near their houses. Approximately 18% of the households own a car, almost three-quarters pay a small fee to their neighbors when they need transportation, and only 6% rely solely on walking for transportation.

The women in Jones contribute significantly to the household economy, as well as fulfilling domestic responsibilities. Although none of the women interviewed work outside of their towns, one quarter of the women produce things that they sell out of their homes, such as food or beverages, and 15% manage a small business such as a small grocery store or corn mill. Over half of the women raise chickens and half have a garden to produce some vegetables and herbs. Although it was difficult to quantify the amount of time that the women dedicate to different activities during a typical day, 83% claimed that they do not have free time for themselves, that they might spend visiting friends or watching television.

Almost 92% of the households are connected to town water systems, most of which draw water from the Colorado River at approximately 850 m. elevation, above the town of Jones. Water is collected in a tank and piped through 10 or 20 cm. pipes for several kilometers, to the communities in the middle and lower basin. The supply system is installed by the men of the town and one man is responsible for its maintenance. To be connected to the water system, each family must pay for part of the materials and pay a monthly water fee.

Most of the houses in the watershed have good kitchen and bathroom facilities that use water. Approximately 94% of the houses have a large sink (*pila*) for washing dishes and clothes, 70% have a shower and 41% have a toilet that uses water (i.e., not a latrine). When water is available, almost all of the women wash their dishes and clothes in the house and their families bathe in the house, except in the towns of El Cajon de Jones, El Peton and La Pepesca, where the majority of the houses do not have a shower.

Figure 8.3 When don't you have running water in your house?



Water shortages are common throughout the watershed, especially during the driest months, from March through April or May. From March through April, over 50% of the households suffer cutoffs in water supply, and in May 32% of the households often do not have water, as shown in Figure 8.3. Cutoffs in water supply are most common in the towns of El Peton, Pata Galana, Jumuzna, La Pepesca and Jones, and they are less common in Jesus Maria, Las Delicias, Las Pozas, and Mal Paso, indicating that the location of the town does not determine the reliability of its water supply, because Jesus Maria and Las Delicias, located in the lower basin, suffer less water supply problems that Jones and El Cajon de Jones, located in the upper watershed. The capacity of the system, in relation to the town's population, the age and condition of pipes and maintenance of the system are all important factors, as well as the quantity of water available at different times of the year.

Even throughout the year, 8% of the households frequently suffer water shortages, often because the water system is insufficient to meet the needs of all of the residents. Variations in water supply at different times of the day, which occur in 42% of the households, indicate that the water supply systems are stressed by heavy water demand in the morning and early afternoon.

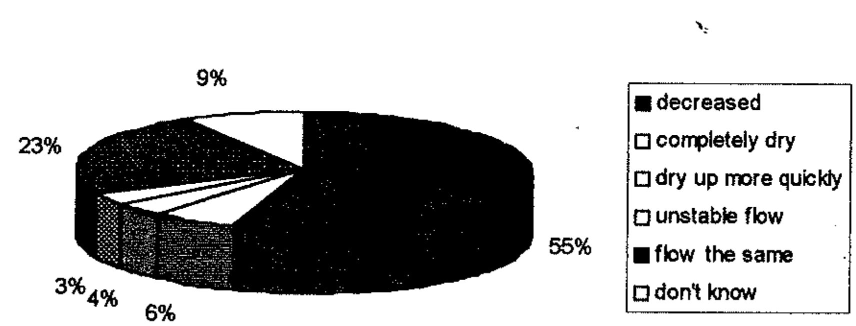
Cutoffs in domestic water supply clearly affect the women's daily activities and have a negative effect on the environment. When water is available in the house, 97% of the women wash their dishes and clothes in the house. However, when water supply is cut off, 29% wash their dishes in the river, 31% wash the family's clothes in the river, and 30% of the families bathe themselves in the river. Because on a weekly basis each family uses an average of 5 bars of dish soap, 3 small bags of detergent and 1 bar of soap for bathing, and half of the women also use chlorine bleach, all of these cleaning materials are thrown directly into the river when domestic water supply is cut off. Because these cutoffs occur most frequently during the dry season, when streamflow is low, the ecological effects of this water pollution are intensified.

Cutoffs in domestic water supply have direct and indirect economic costs, in terms of money spent to purchase or transport water and in term of lost productivity. In addition to the women who wash clothes and dishes in the river, 6% carry water from the nearest river or irrigation channel, back to their houses, walking an average distance of 1 kilometer. Six percent of all of the households purchase potable water when necessary, and in Llano Largo, El Peton and Pata Galana, men travel by car to other towns to bring back tons of potable water.

Several questions were included in the survey about environmental perceptions. When asked about water quality, 81% of the women said that their water system is of good quality, while 16% said it is okay, and 3% said the water quality is poor. In the towns of El Cajon de Jones, La Espinilla, La Pepesca and Las Pozas, none of the women criticized the quality of their water, but in Llano Largo, Llano Verde and Mal Paso, 43% believe that their children get sick from the water.

Almost all of the women support conservation, but many of them did not know that the Sierra de las Minas is a reserve. Not surprisingly, in the towns closer to the reserve, where Defensores has worked (i.e., Jones, El Cajon de Jones, and Mal Paso), the women know more about forest protection. Interestingly, while 42% of the women have heard of Defensores, 76% do not know what Defensores does. Outside of the communities where Defensores has worked, only a few women have heard of Defensores, through television.

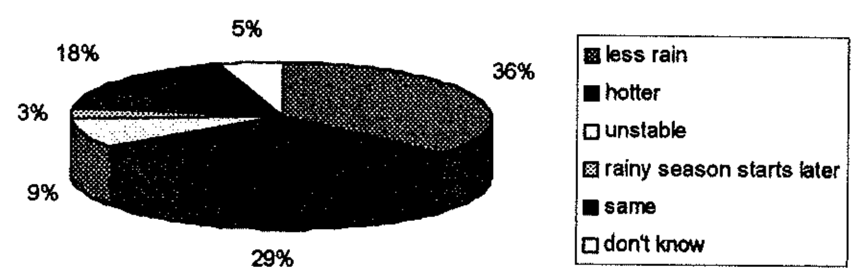
Figure 8.4 Has streamflow changed during you life, and if so how?



Several questions focused on the women's perceptions of environmental change over time. As shown in Figure 8.4, 55% of the women said that streamflow has decreased during their lives, 4% said that the river dries up more quickly during the dry season, 3% said that streamflow has changed and become less stable, and 6% said that the river has dried up completely. This represents a total of 68% of the women who have noticed undesirable changes in streamflow. When asked to explain these changes, interestingly, 39% of the women blamed deforestation, 2% the burning of fields, and a few mentioned increases in water use, while 46% could not explain the changes.

Most of the women have also noticed undesirable changes in climate. As shown in Figure 8.5, over a third said that rainfall has decreased, 29% said that the weather is hotter, 9% expressed concern that the weather is more unstable, and a few mentioned that the rainy season starts later.

Figure 8.5 Has climate changed during you life, and if so, how?



In conclusion, considering the relatively good socioeconomic level at which families are living in the Jones watershed, and their proximity to abundant water resources, it is surprising and very unfortunate that 63% of the households suffer cutoffs in water that threaten the health of their families and the environment and represent economic cost in terms of lost productivity. Clearly, the time that women have to spend hauling dishes and clothes to the river – which is an average of 1 km. from their homes – or carrying water back to their houses is time that they would otherwise be able to spend making things to sell, working in their small businesses, caring for their children, or fulfilling other household responsibilities. Taking into consideration the women's perceptions that streamflow has deceased, that the weather has gotten hotter and drier, and that both of these changes are related to deforestation, there is a very good opportunity here to work more actively with the women in making a direct link between improving water supply and improving watershed management.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The following represent the major conclusions from this research:

1. Water is the base of this agricultural economy, with most agricultural profits made on irrigated land;

2. The maintenance of the dry season flow used for irrigation depends on cloud forest and watershed conservation for the protection of both soil infiltration capacity and horizontal precipitation, with the former being more important than the latter;

3. Cloud forest and watershed protection depend on the development of economic alternatives to unprofitable and unsustainable traditional agriculture in marginal areas; and

4 Water use is currently economically inefficient and wasteful, because management of the resource is inadequate.

9.1.1 Water as the Base of this Agricultural Economy

Irrigated land represents a small but vitally important portion of productive agricultural land in the Motagua Valley. The thin band of irrigated land that runs parallel to the Jones River represents only 30% of all agricultural land and pasture in the watershed but produces 90% of all net agricultural profits. Similarly, in the Hato watershed, irrigated land represents 48% of all productive agricultural land but produces 84% of all profits. Irrigated land is more valuable not only because it supports higher crop yields and more intensive grazing, but because it allows the production of more valuable crops, that cannot be grown on dry land. Assuming that these watersheds are representative of all of the basins on the southern side of the Sierra de las Minas in the arid region of the Motagua Valley from the Comaja through the Los Achiotes, irrigated land produces almost $1 million annually, supporting at least 5,000 rural families.

The results of the regression analysis indicate that increasing average irrigated parcel size from 0.85 to 1.12 hectares would increase the average annual productivity of all agricultural land by $73 per hectare, from $399 to $472, an 18% increase that would certainly help reduce the poverty in this region.

At the same time, the simulation results suggested that even a 10% decrease in dry season flow could cause a loss of $98,355 in Jones and $7,121 in Hato. While water scarcity appears far more critical in Jones – because even a small decrease in water availability would have severe consequences – it is clear that agricultural profits and land ownership are both far lower in Hato, suggesting greater economic vulnerability in this watershed.

Despite the economic value of water, over three-quarters of all of the farmers interviewed said that streamflow has decreased during their lives. While some of this change in streamflow could be explained by the perception of lower precipitation, about 43% of the farmers attribute the change to deforestation. Although almost all of the farmers throughout both watersheds expressed support for conservation, examining the maps of current land use shows inappropriate use of large tracts of land in the upper portion of both basins; Hato is clearly far more degraded. Furthermore, very few farmers appear to be taking steps to protect remaining forest cover or conserve soils on steep slopes.

9.1.2 Importance of Maintaining Dry Season Flow

Both horizontal precipitation and infiltration are important for water supply during the dry season, when water clearly has its highest socioeconomic value. However, to date far more research has focused attention on the unusual and interesting phenomenon of horizontal precipitation. Although fog drip appears to be present at specific sites during dry periods, possibly adding as much as 5-13% "extra water" to the hydrologic cycle, it was not found to increase total precipitation at a statistically significant level. Meanwhile, the paired basin data suggest that horizontal precipitation may have far less quantitative impact on dry season flow than the role of forest soils in storing moisture and maintaining groundwater flow during dry periods. The forested basin in Honduras produced more than twice the flow/unit area of the deforested one during the driest periods of early 1996, while in Guatemala the baseflow of the forested basin was 68% higher than that of the forested one. In both cases, it is likely that at least part of this difference can be attributed to the loss of infiltration and moisture storage capacity as a result of poor soil management.

The need to protect the infiltration and moisture storage capacity of soils is critical in montane regions valued for water production – especially fragile cloud forests. Deforestation and poor soil management in these areas clearly destabilize the flow regime, contributing to dangerous peak flows as well as drastic reductions in dry season flow. Soil degradation is common in Central America, which explains the parched landscapes and dried up springs that are common throughout the region and are causing increasing problems for the rural communities who depend on montane springs and streams for domestic water supply.

Considering that cloud forests may take at least 200 years to regenerate after deforestation (Weaver 1990), conservation efforts essentially represent a struggle to protect hydrologic and ecological resources that could be lost forever. Field research in Cusuco has indicated that frequent cloud cover and the coinciding presence of cloud forest have, over the past several decades, moved at least 200 meters up in altitude on both sides of the park, representing a loss of hundreds of hectares of cloud forest and water recharge zone. For the sake of future generations, education about the importance of cloud forests and action to protect them are imperative.

9.1.3 Need to Develop Economic Alternatives to Unsustainable Agricultural Practices

In both Jones and Hato, steep, fragile soils are being used inappropriately and unsustainably in the upper watershed. The 654 hectares of pasture in the upper central portion and over 600 hectares of secondary brush and agricultural land in the upper western portion of the Jones watershed represent serious threats to soil fertility, agricultural productivity and watershed protection. Meanwhile, Figure 6.7 demonstrates that the Hato watershed has been settled and used far more intensively than Jones, with deforestation reaching as high as 2500 m. elevation. The word "Hato" means herd, and both the name and the predominance of land classified as dry pasture suggest that much of the land was once used for extensive grazing, although the survey results show that very little land is currently used as pasture.

Traditional annual crops grown on dry land in the middle and upper portions of these watersheds are obviously not profitable when one calculates the true economic value of family labor. The fact that these crops are grown extensively indicates a lack of other economic opportunities. Clearly, these farmers would be better off if they could grow other crops, develop small agroindustries such as the coffee and sugar mills – which are more profitable than annual or perennial crops or pasture – or other businesses, or work elsewhere and purchase their corn. The number of young adults who leave Jones to go to the United States clearly indicates the lack of economic opportunities in this region, which fuels the vicious cycle of poverty and watershed degradation.

The large variance in net agricultural profits also suggests a strong need for agricultural extension programs to increase profits in productive areas and decrease the need to deforest and cultivate marginal areas. The regression analyses showed that agricultural productivity is higher on larger parcels of land managed solely by the owner (i.e., not rented or co-managed), where more labor is invested. This suggests that especially small, poor farmers could increase their profits by improving their land management.

9.1.4 Water Use Currently Inefficient and Wasteful

Water use in this area demonstrates a good example of a "common property resource," in which resource use is open to the public but a finite amount of the resource is available, and lack of management causes inefficiency and waste. In zone 1 of Jones, the farmers say that the person who gets up earliest in the morning gets the most water, and there is no organization of water use. The result of this is that the farmers in zone 1 use 50% more water per hectare of pasture than those in zone 2 and twice as much as those in zone 3, although they do not make higher profits from this extra water. More than three times as much water is used for traditional annual crops than any other land use, although they are clearly far less profitable. Many farmers in zone 3 said that they often cannot irrigate during the peak of the dry season, because almost no water reaches the bottom of the watershed.

It is clear in this case that water is being overexploited and wasted by those with the best access to it (in zone 1), although it could be used more profitably downstream. This problem often causes conflicts; in many cases farmers from zone 3 will walk upstream and remove the rocks used to dam up and divert streamflow in zones 2 and 1, so that more water will reach zone 3. In this volatile region, people have been killed over such water conflicts. Collaboration on the watershed level is desperately needed to resolve this problem.

Water appears to be far more abundant in the Hato watershed, reducing the possibility for conflict over water use. However, the amount of water used appears to be excessive and wasteful. In zone 2, it is estimated that over 156,000 m^3 of water are used annually to irrigate each hectare of perennial crops and an average of 35,000 m^3 per hectare are used for all agriculture in zone 3.

Irrigation by gravitation is far more inefficient and wasteful than aspersion or drip irrigation (which involve capital costs), because of losses to evaporation and infiltration.

9.2 RECOMMENDATIONS

The following recommendations represent actions suggested to promote cloud forest and watershed protection and more efficient water use:

1. Promote organization on the watershed level to increase awareness of the linkages between economic development and watershed protection and to generate collaborative action;

2. Develop incentives (policy, financial, and social) for watershed protection through economic development; and

3. Conduct further research on cloud forest hydrology and the ecological effects of water diversion.

9.2.1 Increase Awareness and Organization for Watershed Management

The farmers we interviewed were clearly aware of their strong dependence on water resources for irrigated agriculture, and most support conservation, because they understand on at least a simple level the linkage between forest protection and maintenance of the dry season flow used for irrigation. However, this awareness has not been translated into action, due to lack of organization and collaboration on the watershed level. The simulation results demonstrate very clearly how continual advance of the agricultural frontier in the upper watersheds could have severe economic consequences downstream.

Water is clearly a common property resource, for which wise and efficient management requires collaboration between groups and the channeling of resources to support more sustainable land management and more efficient water use. Watershed organizations should be formed, to bring together not only landowners but also local political leaders and business representatives with access to the government and private resources needed to develop and implement watershed management plans.

9.2.2 Develop Incentives for Watershed Protection and Economic Development

To improve watershed management, an analysis should be conducted to suggest market, voluntary and legal incentives that could be developed to promote the protection and sustainable management of remaining forest, encourage the development of agricultural practices that are economically and ecologically more sustainable, and generally expand economic opportunities in these impoverished areas. A few general ideas for incentive programs are presented below. Incentives should be implemented initially through a pilot project in watershed management in one or both of the study watersheds.

A feasibility analysis should be conducted to determine the potential for development of more agroindustry and other small businesses that will reduce pressure on upper watershed land. Low-interest loans should be provided to promote small-scale hydropower development for small businesses in upper watershed areas adjacent to the reserve. It is clear that small-scale hydropower provides sizable socioeconomic benefits to rural communities if assistance can be obtained to cover the initial costs. The annual value of the electricity provided for 41 families in the upper Hato basin was estimated at $5,231, or $128 per family, in an area where connection to the national electrical grid would be prohibitively expensive.

A direct link should be established between water use and watershed protection, so that all water users contribute in some way to maintenance of the resource. Industrial water users should be encouraged (and eventually required) to contribute financially to watershed protection, while poor farmers, that receive domestic supply and irrigation, should be given economic development assistance in exchange for watershed protection.

Although it was not possible to estimate the socioeconomic value of industrial water, it is clear that none of the 37 companies located in the Motagua Valley pay a cent for the water they use, nor is the quantity of water that they withdraw from rivers or wells regulated in any way. Industrial water use is small compared to irrigation, but data obtained from one company indicated that the net profit that some of these companies – especially the bottling companies – obtain from the resource represents almost three times the value of production costs.

None of these companies are taking any action to protect the future of this resource, which in several cases is the base upon which they are making profits. Defensores should develop a fundraising campaign directed specifically to these industries, in which those companies that support watershed protection and restoration are given public recognition for their efforts. Just as supporting the Olympic Games is a source of pride and profit for many multi-national companies such as Pepsi, Kodak and Nike, protecting the water of the Sierra for future generations (and future profits) should be a source of national pride, as well as a good private investment, for these companies.

Improvements in watershed management could be promoted through collaboration with local communities to improve potable water supply. Many of the communities located in the buffer zone around the reserve have inadequate potable water systems. The survey conducted in Jones showed that despite the abundance of high-quality water flowing from the reserve, more than half of the households suffer cutoffs in water supply that cause many of the women to wash clothes and dishes in the river, degrading water quality and increasing exposure to disease. Protection of the reserve has been promoted on the basis of the abundant, high-quality water that flows from the Sierra. Yet, unless the communities surrounding the reserve are provided adequate, reliable, consistent domestic water supply, they may reasonably question the benefits that the water resources of the Sierra provide to them. A small grants or revolving loan fund could be established in which communities qualify for a grant or loan by participating actively in watershed management.

A similar program could be established in which communities are provided low-interest or no-interest loans to convert gravitational irrigation systems to aspersion systems, allowing them to increase their agricultural profits by irrigating more land, in exchange for allowing the regeneration of degraded upper watershed areas. In addition, perennials, such as fruit orchards, could be promoted, because they are not only more ecologically sustainable than annual crops but also more profitable, because they require little investment in either agricultural inputs or labor.

9.2.3 Conduct Additional Hydrology and Aquatic Ecology Research

Further research should be conducted on the hydrologic effects of deforestation. The effect of deforestation on streamflow has been studied very little in tropical cloud forests (or even in other montane tropical forests), despite widespread perceptions that streamflow is decreasing due to deforestation. Over 90% of the farmers in both watersheds claim that streamflow has decreased during their lives and 43% of them blame deforestation. However, forest hydrology literature provides strong arguments that soil degradation, rather than the removal of trees, is at the root of this problem. Hydrology and soil research is needed to determine what land use and edafic factors contribute significantly to watershed degradation and socioeconomic research is needed to determine what soil conservation techniques can provide cost-effective solutions in montane agricultural areas where forest regeneration is not possible.

Longer-term research on horizontal precipitation is also needed. The hydrology data suggest that horizontal precipitation does occur during the dry season, at the highest sites on the southern side of the Sierra de las Minas and on the northern side of Cusuco National Park, reducing or canceling out the loss of water to canopy interception, and possibly increasing total precipitation for short periods of time in specific sites. However, they do not show that horizontal precipitation increases total precipitation at a statistically significant level. More intensive sampling should be conducted at these sites, because one hydrologic year is a short period of time for studies such as this, and because more intensive sampling is needed to draw stronger conclusions about the significance of horizontal precipitation at these sites. However, care should be taken not to generalize from these specific sites to the cloud forest in general, since there are clearly many site-specific differences.

Long-term climate data is also vital not only to understand hydrology but also to learn about the ecology of the region and to develop sound land management plans. A network of simple, inexpensive climate stations should be established around the reserve, to collect data on at least precipitation, temperature, and relative humidity.

Research should be initiated to determine the ecological impact of water diversion. Throughout the Jones watershed, at the peak of the dry season, 80-97% of streamflow is diverted for irrigation. In the middle and lower Hato watershed, 50-80% of streamflow is diverted. To date, no research has been conducted to examine the ecological effect of high water diversion, which drastically reduces streamflow during the period of the year when it is lowest.

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